HOUSEHOLD PHYSICS LABORATORY MANUAL

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HOUSEHOLD PHYSICS LABORATORY MANUAL

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PREFACE

This manual is written to accompany the author's text, *Household Physics*, and is the result of an effort to differentiate between the laboratory work given for students of home economics and that for students in a general arts course. The twenty-five experiments which are included have been selected from a list of approximately forty experiments which have been used from time to time in this laboratory.[1] More experiments are included than are generally used in a household physics course in order that the instructor may choose those best adapted to his laboratory.

Experiments have been chosen which are quantitative and capable of yielding good results, and the use of modern equipment which will be encountered in everyday life has been emphasized. The experiments are designed for a three-hour laboratory period; in general, they are divided into parts, both to emphasize the organization of the material and to enable the instructor to make a suitable selection for a particular group of students or for a shorter laboratory period; in most cases, parts of the experiment may be omitted without loss of continuity. Instructions which apply to the local situation have been reduced to a minimum, but where they have been included it is hoped that they will suggest comparable situations in other laboratories.

The apparatus required is listed at the beginning of each experiment, and additional notes for the instructor are given in Appendix B. A brief summary of the theory involved is given, and a reference to the author's text *Household Physics* is included. Corresponding references to other texts which may be available may be supplied by the instructor. The procedure is given in considerable detail with the idea of encouraging systematic work. The questions involve theory, procedure, and interpretation of data. Some questions, the answers for which are not found in the experiment, have been included to lead the student to connect the laboratory experiment with his everyday experience. The answers to the questions may be written as a part of the laboratory report, or the questions may be used as a guide in preparation for a quiz over the experiment. The author believes a better understanding of the experiment will result from thinking through the answers to the definite questions than from merely performing the experiment and writing a general discussion of it. It is hoped that the questions given will suggest others to the instructor. Data sheets are included to aid the student in recording data in an orderly manner. Some teachers, no doubt, will feel that the student should make his own data sheet, but most of the students who take this course have had little, if any, training in recording data, and the author feels that the student will profit by using these forms.

No great originality is claimed for this manual. While very few physics laboratory manuals have been written for home economics students, any physics experiment must, of necessity, be based on standard physical measurements. Material has been selected from various sources and adapted to the course in household physics. Manuals which have been especially useful are:

Ingersoll and Martin: *Experiments in Physics*
Schneider and Ham: *Experimental Physics for Colleges*
Black: *New Laboratory Experiments in Practical Physics*
Williams: *Experimental Physics*
Taylor, Watson, and Howe: *General Physics for the Laboratory*

[1] Copies of the experiments which have not been included may be obtained from the Department of Physics, Kansas State College, Manhattan, Kansas.

Morrison and Morrison: *Experimental Physics*
Chicago Apparatus Company: *Milvay Manual*
McCracken: *Selected Physics Topics*

The author is indebted to Sister M. Ambrosia, Ph.D., of Marygrove College, who sent a copy of her mimeographed experiments, and to Dr. E. Frances Johnson, of Rockford College, who suggested some of the material for the experiment on Illumination. She is also indebted to all of her colleagues for their assistance in preparing the manual. She is especially indebted to Dr. A. B. Cardwell, Head of the Department of Physics, for his interest and coöperation, and to Dr. J. Howard McMillen, Professor L. E. Hudiburg, and Miss Wilma Hilt for their assistance in the choice of material and their valuable criticisms of the entire manuscript.

The author will sincerely appreciate the suggestions and criticisms of those who use the manual, and she will be glad to have any errors called to her attention.

MADALYN AVERY

MANHATTAN, KANSAS
February, 1940

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Experiment 1

HOUSEHOLD WEIGHTS AND MEASURES

PURPOSE: To test the accuracy of a household scale and the accuracy of household liquid, dry, and length measures; also to check the weights of packages of groceries and to note standard can sizes.

APPARATUS: Household scale, household capacity measures including quarts, cups, and serving spoons, cloth tape measure, wooden yardstick, standard English weights, standard liquid and dry measures, standard spoons, standard yardstick, packages of groceries, canned goods in various sized cans.

THEORY: A household scale of the spring balance type is shown in Fig. 1-a. When an object is placed on the scale, the platform is pushed down. This pushes the bar *A* down and elongates the spring *B*. The notched strip *C* moves at the same time and turns the wheel *D*, which turns the pointer on the scale face. The action of this balance is based on Hooke's law, which states that "**within the elastic limit of the spring, the stretch is directly proportional to the applied force.**"

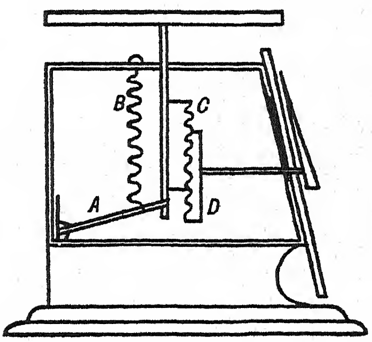


FIG. 1-a. A household scale of the spring balance type.

Household scales are made in various capacities up to 50 or 60 lb. Many of them have a capacity of 24 or 25 lb., which is a satisfactory amount for most households. The pound divisions are subdivided, usually into ounces or fractions of an ounce. Most scales have a screw adjustment by means of which the pointer may be set to read exactly zero when the scale pan is empty.

Many foods are sold in packages which have the weight of the contents stamped on the package. Other foods are weighed by the local grocer, and any desired amount may be purchased. The weights of these packages should be checked for accuracy occasionally. Canned foods are always sold in standard sized cans with the weight of the contents stamped on the can. Fruit juices are sold in cans which are labeled with the fluid capacity of the can. The following table gives the numbers of the sizes which are in most general use and the allowable variation in weight for each:

No. 1 —10.5 oz. to 1 lb.
No. 2 —1 lb. 2 oz. to 1 lb. 4 oz.
No. $2\frac{1}{2}$—1 lb. 12 oz. to 1 lb. 14 oz.
No. 3 —2 lb. to 2 lb. 4 oz.
No. 10—6 lb. 4 oz. to 6 lb. 14 oz.

In general, foods are more accurately measured if they are weighed rather than measured in dry measures. For example, a peck of potatoes or of apples is supposed to weigh a given number

Experiment 1

Name______________________________

HOUSEHOLD WEIGHTS AND MEASURES

Location____________________________

Date______________________________

I. Household Scale

1. General description

Scale number =
Manufacturer's name =
System of units in which scale is calibrated =
Capacity of scale =
Numerical value of smallest scale division =

2. Testing the calibration of the scale

Standard Weights	Scale Readings	
0 lb.	0 lb.	0 oz.
2	____	____
4	____	____
6	____	____
8	____	____
10	____	____
12	____	____
14	____	____
16	____	____

3. Plot curve on coordinate paper

II. Checking Accuracy of Commercial Packages

Article	Scale Reading	Correct Weight	Store Weight	Error Made by Store

III. Standard Can Sizes

Name of Company	Name of Food	Number of Can

Name of Company	Name of Fruit Juice	Fluid Contents

IV. Weight Method versus Capacity Method

____

____

____

V. Liquid Measures

Name of Measure	Laboratory Number	Variation from Standard
Quart		
Cup		
Cup		
Cup		
Tablespoon		
Tablespoon		
Teaspoon		
Teaspoon		

VI. Length Measures

Standard yard = 36 in.

Tape measure (slight tension) = ______

Tape measure (considerable tension) = ______

Wooden yardstick = ______

Experiment 2

DENSITY AND SPECIFIC GRAVITY

PURPOSE: To determine the density and specific gravity of several materials, some of which are heavier and some lighter than water.

APPARATUS: Balances and weights (English and metric), a ruler, large beakers, 100 c.c. graduate, 1000 c.c. graduate, pieces of wood of simple geometric form, small iron sinker, irregularly shaped pieces of metal, spoons, large iron mass (10 kg.), hydrometers, hydrometer jars containing various liquids.

THEORY: The **density** of a material is its mass per unit volume. The **specific gravity** of a material is the ratio of its density to the density of water. Density may be measured in such units as grams per cubic centimeter, pounds per cubic inch, or pounds per cubic foot. The mass is found by weighing the object on a suitable scale. The volume may be found in various ways. If the object is of a simple geometric form, such as a cube, a parallelopiped, a sphere, or a cylinder, its volume may be computed from its dimensions. Whether the object is of regular or irregular shape, its volume may be found (a) by suspending the object by a fine cord in a graduate containing a liquid (usually water) and noting the increase in the reading of the graduate; or (b) by weighing the object first in air, and then suspended in water. (Other liquids may be used.) The loss of weight divided by the density of water gives the volume.

$$\text{Volume} = \frac{\text{Loss of weight}}{\text{Density of water}}.$$

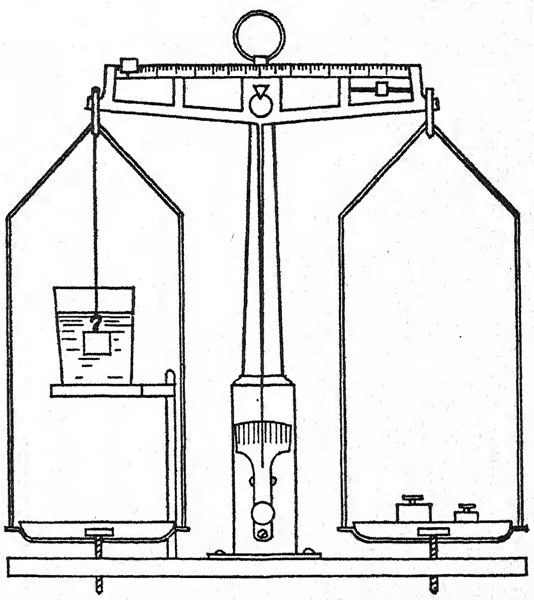


FIG. 2-a. Finding the loss of weight due to the buoyant effect of a liquid.

This last method is based on **Archimedes' Principle, which states that a body suspended in water is buoyed up by a force equal to the weight of the displaced water.**

If the object is lighter than water, it may have a sinker attached which will pull the object into the water. If a graduate is used, readings are recorded (a) with the sinker suspended under the surface of the water and (b) with the sinker and the object suspended under the surface of the water. If one is using the loss of weight method, the sinker is attached to the object and both are hung on the scale with the beaker of water at such a level that the sinker is immersed but the object is not, and the weight is then recorded. Then both sinker and object are immersed and the weight is recorded. The loss of weight is the buoyant force of the water on the object being tested.

The specific gravity of a liquid may be obtained by use of a hydrometer, which is a glass instrument consisting of a cylindrical stem with a graduated scale and a weighted bulb to make it float upright. The liquid is poured into a tall jar and the hydrometer lowered into the liquid until it floats freely. The specific gravity may be read on the scale at the surface of the liquid. A special form of hydrometer is used for testing the specific gravity of the acid in a storage battery. The hydrometer is contained in a glass tube which is fitted with a rubber suction tube at the bottom through which the liquid is drawn up into the glass tube by means of a rubber bulb at the top. The hydrometer is provided with glass projections which keep it centered and prevent its clinging to the walls of the glass tube. A similar hydrometer is used for testing the specific gravity of anti-freeze solutions for automobile radiators. If the specific gravity and the temperature of the solution are known, its freezing point may be determined by consulting a chart which accompanies the hydrometer.

Reference: Avery, pages 17–25.

PROCEDURE: ***Density and Specific Gravity.*** 1. Weigh a piece of wood which has a simple geometric form. Determine its dimensions and calculate its volume. Calculate the density and the specific gravity. Do this (a) in metric and (b) in English units.

2. Weigh an irregularly shaped piece of metal. Find its volume by noting the amount of water displaced in a graduate. Calculate the density and the specific gravity of the metal. Use metric units.

3. Using the same object that was used in the preceding test, find its volume by finding the loss of weight in water. (Use an overhead beam balance with adjustable platform and suspension hook.) Calculate the density and the specific gravity. Use metric units.

4. Find the density and the specific gravity of a teaspoon to determine whether or not it is pure silver. Use the loss of weight method and work the problem in metric units.

5. Find the density and the specific gravity of a large piece of iron. Use the loss of weight method and work the problem in English units.

6. Find the volume of the piece of wood used above by attaching a sinker and immersing the wood in water in a graduate. Use metric units. (The small notches are cut in the wood so that the thread may be placed where it will not slip.)

7. Find the volume of the same piece of wood by the loss of weight method. Use metric units. (Compare results of 1, 6, and 7.)

8. Find the specific gravity of several liquids by means of hydrometers. (Water, gasoline, battery acid, anti-freeze solutions, copper sulphate, salt solutions, sugar solutions, milk, and syrup may be used.)

QUESTIONS:

1. Why are density and specific gravity problems easier to solve in metric than in English units?
2. Why is water generally used for the liquid in the graduates, or in the beakers for the loss of weight method?
3. In which liquid, water or mercury, will a piece of aluminum appear to weigh the less? Why?
4. Will there be any difference in the readings if some liquid other than water is used in the graduate when one is finding the volume of the object by noting the volume of liquid displaced?
5. How do the calculations for finding the volume from loss of weight differ if some liquid other than water is used?
6. What is the effect of an increase in temperature on the specific gravity of a liquid?
7. What is the apparent loss of weight if 15 cubic inches of aluminum are weighed in air and then in water?

Experiment 2

Name____________________

DENSITY AND SPECIFIC GRAVITY

Location____________________

Date____________________

1. Density and specific gravity of a simple geometric solid

	METRIC	ENGLISH
Mass of object		
Dimensions		
Volume		
Density		
Specific gravity		

2. Density and specific gravity of an irregularly shaped object, using a graduate to find the volume

Mass of object	
1st reading of graduate	
2nd reading of graduate	
Volume of object	
Density	
Specific gravity	

3, 4, 5. Density and specific gravity of irregularly shaped objects—volume found from loss of weight of object in water

	3.	4. SPOON	5. IRON
Mass of object			
Weight of object in water			
Loss of weight when object is submerged			
Volume of object			
Density			
Specific gravity			

6. Volume of an object lighter than water, using a graduate to find the volume

1st reading of graduate	
2nd reading of graduate	
Volume of object	

7. Volume of an object lighter than water by loss of weight

Mass of object	
Weight—object in air, sinker in water	
Weight—object and sinker in water	
Loss of weight when object is submerged	
Volume of object	

8. Specific gravity of liquids with hydrometer

LIQUID	SPECIFIC GRAVITY

Experiment 3

GRAPHICAL COMPOSITION AND RESOLUTION OF FORCES

PURPOSE: To solve force problems by graphical methods.

APPARATUS: Force table, weights, weight holders, spring balance, protractor, adjustable inclined plane, Hall's carriage.

THEORY: A force may be represented graphically by an arrow which will show the direction along which the force acts and, if drawn to scale, the magnitude of the force. Two or more forces may be combined into one force, called the **resultant.** The original forces are the **components** of the resultant force. The **equilibrant** is a force equal in magnitude but opposite in direction to the resultant, or in other words, it is the force which will just balance the resultant. Also, any given force may be resolved into two or more components.

1. Draw a horizontal line of indefinite length and mark a point A on this line.
2. At A construct an angle θ equal to the angle between the forces.
3. Choose a linear scale for the forces, keeping the scale as large as the available space will allow; for example, a line one inch long may represent a force of 2 lb.
4. Calculate the lengths of the lines needed to represent the magnitudes of the two forces, AB and AC, and mark these lengths on the sides of the angle θ.
5. Complete the parallelogram, having AB and AC as sides. Draw a diagonal R from A to the opposite corner of the parallelogram.
6. Measure the length of the diagonal R, and by means of the scale you chose in step 3, calculate the resultant force R. The equilibrant is equal to the resultant in size but opposite in direction.

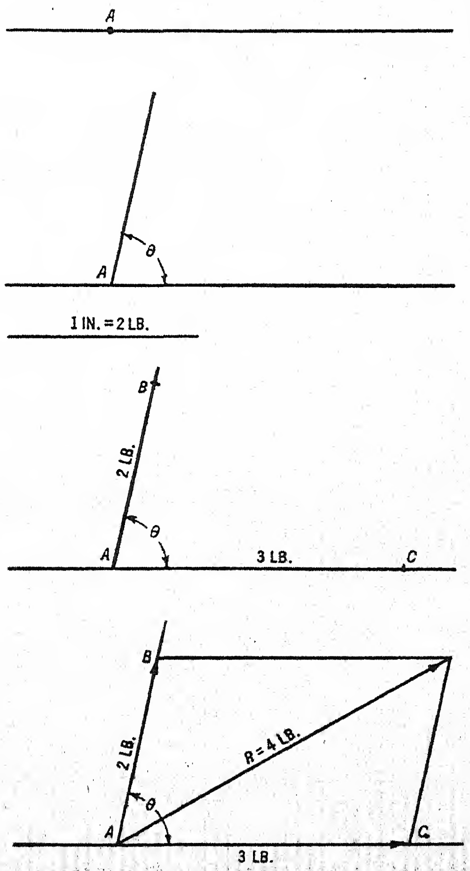


FIG. 3-a. Construction of a force parallelogram.

If two forces act in the same straight line or in parallel lines, and in the same direction, their resultant is equal to their arithmetic sum and its direction is the same as that of the components. If two forces act in the same straight line or in parallel lines, but in opposite directions, their resultant is equal to their algebraic sum and its direction is the same as that of the larger component. If two forces act at an angle with each other, the resultant may be found graphically by completing a parallelogram, the sides of which are drawn proportional to the forces. The resultant force arrow is found by drawing the diagonal from the point of application of the forces to the opposite corner of the parallelogram. Fig. 3-a shows how the parallelogram may be constructed. A force table is an apparatus which is used to demonstrate the composition of forces. When the forces are balanced, the ring R is centered about the pin C. The angles may be read directly from the graduations around the circumference of the table. Instead of finding the resultant directly, the equilibrant is found, and the resultant is equal to the equilibrant in magnitude but opposite in direction.

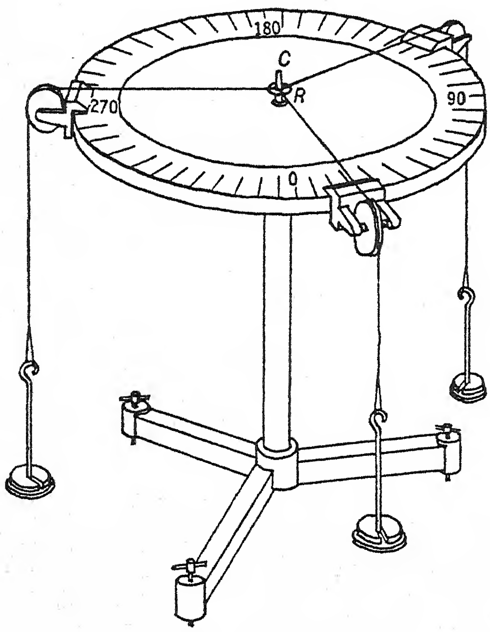


FIG. 3-b. A force table.

If a given force is to be resolved into components, the directions of the components must be given. For example, a force which makes a given angle with the horizontal may be resolved into horizontal and vertical components, or the force due to the pull of gravity on an object which is on an inclined plane may be resolved into components parallel and normal to the plane. To resolve a force into horizontal and vertical components, construct a horizontal line passing through one end of the force arrow and a vertical line passing through the other end. These intersect and thus the lengths of the component force arrows are determined. See Fig. 3-c. To resolve a vertical force into components normal and parallel to an inclined plane, construct two lines, one normal to the plane and passing through one end of the force arrow, and the other parallel to the plane and passing through the other end of the force arrow. These intersect and thus the lengths of the component force arrows are determined. See Fig. 3-d. Usually the di-

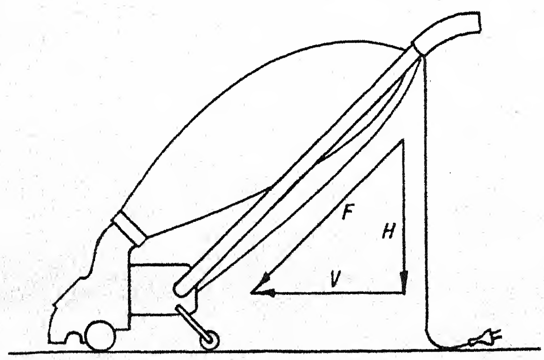


FIG. 3-c. Resolving a force into horizontal and vertical components.

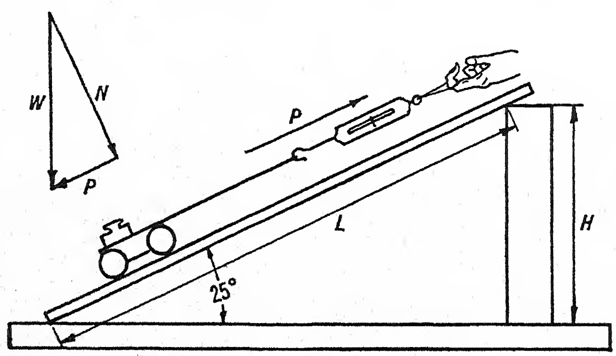


FIG. 3-d. Resolving a vertical force into components parallel and normal to an inclined plane.

rections of the components may be determined by inspection, but they will always lead from the point of application toward the opposite end of the original force arrow.

Reference: Avery, pages 25–27.

PROCEDURE: ***I. Composition of Forces.*** 1. Weigh two objects, A and B, and record the weights. Hang these two objects on one of the cords on the force table. Add weights to a weight holder on another cord placed so that it forms a straight line with the first cord. Adjust the weights until the ring is centered about the pin. Count the weights, including the weight holder. Compare this amount with the sum of the weights of the two objects. Make a graphical solution.

2. Hang the two objects on cords placed so that they form a straight line. Hang a weight holder on the lighter object and add weights until the ring is centered about the pin. Count the weights, including the weight holder. Compare this amount with the difference in the weights of the two objects. Make a graphical solution.

3. Hang the two objects on cords which make an angle of 30° with each other. Hang a weight holder on a third cord. Add weights and adjust the position of the cord until the ring is centered about the pin. Count the weights, including the weight holder. Solve for the resultant graphically. Compare the size of the resultant with the experimental value of the equilibrant.

4. Hang the two objects on cords which make an angle of 90° with each other. Hang a weight holder on a third cord, add weights, and adjust the position of the cord until the ring is centered about the pin. Count the weights, including the weight holder. Solve for the resultant graphically. Compare the size of the resultant with the experimental value of the equilibrant. Check the value of R, using the relationship

$$R = \sqrt{A^2 + B^2}.$$

II. Resolution of Forces. 1. By means of a cord attach a spring balance to some object in the laboratory, for example, a vacuum cleaner. Find the force required to move the object when the angle between the cord and the floor is 45°. Solve graphically for the horizontal and vertical components of the force. Find the force required to move the object when the force is applied horizontally. Compare this force with the horizontal component of the force acting at 45°.

2. Adjust the inclined plane to an angle of 25°. Put a heavy object in the Hall's carriage and determine the total weight. Place the carriage on the plane, attach a spring balance to the cord, and note the force required to hold the carriage in position. Knowing the weight of the carriage and the angle of the plane, solve graphically for the force parallel to the plane. Compare this with the experimental value. Find the force normal to the plane from the graphical solution. As a check, use the graphical values for the forces parallel and normal to the plane and solve for the weight of the carriage, using the rule that the sum of the squares of the sides of a right triangle is equal to the square of the hypotenuse. Compare this value with the weight obtained by weighing the carriage.

QUESTIONS:

1. Two forces, one of 10 pounds and one of 15 pounds, act horizontally and to the right. Find the resultant and the equilibrant. Solve graphically.
2. A force of 10 pounds acts horizontally to the left and a force of 15 pounds acts horizontally, but to the right. Find the resultant and the equilibrant. Solve graphically.
3. A force of 10 pounds acts horizontally to the right and a force of 15 pounds acts at right angles to it and is directed upward. Find the resultant graphically and check it mathematically.

4. As the angle between two forces decreases from 180° to 0°, does the value of the resultant increase or decrease? Make a series of sketches to illustrate your answer.
5. If a picture which weighs 20 pounds is hung by two vertical cords, what is the tension in each cord? Will it make any difference whether the picture is hung with its longer dimension in a horizontal or a vertical line?
6. If the above picture is hung by a cord which passes over a nail and makes a right angle at the nail, what is the tension in the cord? Solve graphically.
7. If the force due to the weight of an object on an inclined plane is resolved into components normal and parallel to the plane, are the component forces ever greater than the weight of the object?
8. Resolve a force of 100 pounds acting at an angle of 30° with the horizontal into horizontal and vertical components. What is the relation between the vertical component and the force acting at an angle of 30°?

Experiment 3

Name____________________

Location____________________

Date____________________

GRAPHICAL COMPOSITION AND RESOLUTION OF FORCES

I. Composition of Forces

1. $A =$ __________ Graphical solution

$B =$ __________

$A + B =$ __________

$R =$ __________

2. $A =$ __________ Graphical solution

$B =$ __________

$A - B =$ __________

$R =$ __________

3. $A =$ __________ Graphical solution

$B =$ __________

Exp. $R =$ __________

Graph. $R =$ __________

4. $A =$ __________ Graphical solution

$B =$ __________

Exp. $R =$ __________

Graph. $R =$ __________

$R = \sqrt{A^2 + B^2} = \sqrt{\qquad} =$ __________

II. Resolution of Forces

1. Resolving a force into horizontal and vertical components

Force acting at 45° with horizontal (experimental)	
Horizontal component (graphical)	
Vertical component (graphical)	
Horizontal component (experimental)	

Graphical solution

2. Resolving a vertical force into components normal and parallel to an inclined plane. (Angle of inclination = 25°)

Weight of carriage plus contents (experimental)	
Force parallel to plane (experimental)	
Force parallel to plane (graphical)	
Force normal to plane (graphical)	
Weight of carriage plus contents (by calculation)	

Graphical solution

Experiment 4

BREAKING STRENGTHS OF TEXTILE MATERIALS

PURPOSE: To test the breaking strengths of fibers, sewing threads, and fabrics.

APPARATUS: Jolly balance and a set of weights, thread testing apparatus, cloth testing apparatus, wool fibers, cotton fibers, a selection of various kinds, colors, and sizes of threads, a selection of various kinds of fabrics, eyelets for mounting the fibers, a wire rack on which to hang the eyelets while the glue dries, quick drying glue, shears, ruler, microscopes.

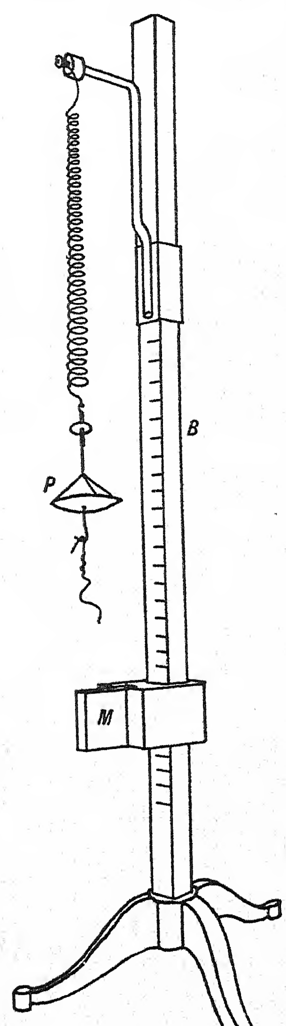


FIG. 4-a. A Jolly balance.

THEORY: The **breaking strength** of a given sample is the force required to break the sample when force is applied slowly. The **tensile strength** is equal to the breaking strength per unit cross-sectional area for fibers or threads, and per unit width for cloth.

Fibers may be classified into two general groups, natural and artificial. The natural fibers are further subdivided into (a) animal fibers, such as silk and wool, and (b) vegetable fibers, such as linen and cotton. The artificial fibers are made of cellulose and there are many kinds, all of which may be included in the general term " rayon." Wool, cotton, and linen fibers are cellular, but silk and rayon are non-cellular. Some of the factors which affect the strength of a fiber are the kind of fiber, the physical and chemical treatment it has received, its age, and the relative humidity to which it is subjected.

Sewing threads are made of various kinds of fibers. Factors which affect the strength of a thread are the strength of the fibers used, the length of the fibers, the twist of the thread, its size, and the chemical processes, such as dyeing, bleaching, and mercerizing, which have entered into its manufacture.

Fabrics may be woven from yarns made of any of the fibers listed above. The strength of a fabric depends on the strength of the yarns from which the fabric is made, the type of weave, the number of yarns per inch, and the finishing processes used.

Fibers are prepared for testing by gluing individual fibers to wire eyelets. When the glue is dry, the fibers are broken on a Jolly balance. A Jolly balance consists of an upright graduated bar B, with a spiral spring attached to a support at the top. A small weight pan P is attached to the lower end of the spring. By noting the elongation of the spring caused by a given weight, the number of grams required to stretch the spring one centimeter may be calculated. This force per centimeter is known as the **force constant** of the spring. An eyelet is then attached to the hook on the bottom of the weight pan; the fiber is pulled just taut and held with the thumb against the movable

marker M. The reading at the top of the marker is recorded; then by moving the marker, a steady pull is applied to the fiber until it breaks. The reading at the top of the marker is again recorded. Knowing the force constant and the elongation of the spring, the breaking strength of the fiber may be calculated.

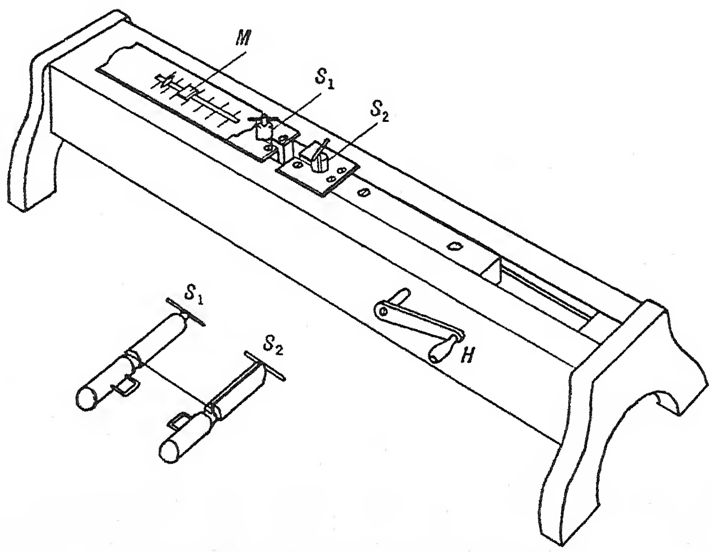


FIG. 4-b. A thread testing apparatus.

The apparatus for testing the breaking strength of threads consists essentially of a spring balance, fitted into a framework, by means of which the force applied to a thread to break it may be measured. The thread is fastened to the spindles S_1 and S_2. When the handle H is

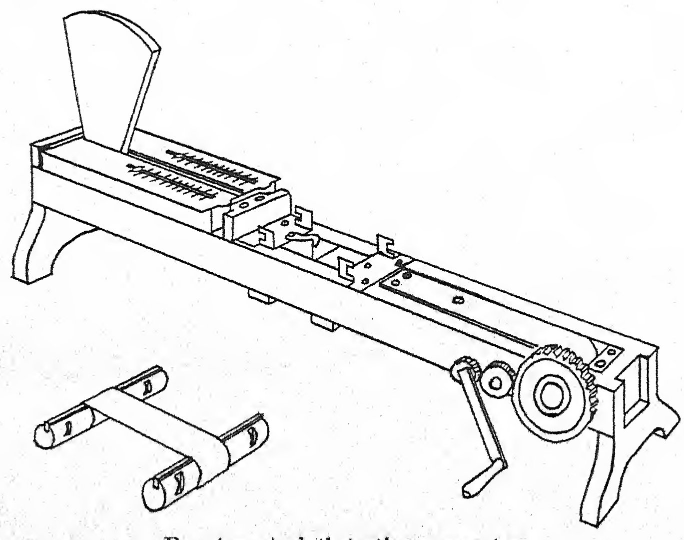


FIG. 4-c. A cloth testing apparatus.

turned, the force is transmitted through the thread to the spring. As the pointer is moved down the scale, the marker M is moved with it. When the thread breaks, the pointer flies back to zero, but the marker is left in position to indicate the force exerted on the thread. It must be moved back to zero before a second thread is tested.

The apparatus for testing the breaking strength of cloth is essentially the same as that for testing threads, except that the spring balances are stronger. The wedge-shaped board keeps the indicator on the balance from going back to zero when the sample breaks. The board may be removed easily by applying a small force to the spring by means of the metal hook that is just below the clamps which hold the cloth. The specimens are cut (not torn) $1\frac{1}{4}$ in. in width if there are 50 or more yarns per inch, and $1\frac{1}{2}$ in. in width if there are fewer than 50 yarns per inch. Each specimen should be raveled to 1 in. in width by taking from each side approximately the same number of yarns. Two sets of five specimens each are required, one set cut lengthwise and one crosswise of the material. No two of the five specimens in any one set should contain the same yarns. Specimens should be taken not nearer the selvage than one-tenth the width of the fabric.[1]

The student will not have enough data at the end of the experiment to draw any definite conclusions as to the breaking strength of any given kind of material. This experiment will show how the tests can be made and will show that an average of many tests is required before a general statement can be made concerning the breaking strength.

Reference: Avery, pages 17 and 25.

PROCEDURE: *I. Fibers.* 1. Each student should mount two wool fibers and three cotton fibers. Dip the straight end of the eyelet into glue, leaving just enough on the wire to make it sticky. Wind the fiber two or three times around the wire and hang the eyelet on the wire rack furnished for that purpose. Let the glue dry for at least half an hour. (Meanwhile go ahead with Parts II and III; then finish testing the fibers.)

2. Find the force constant of the Jolly balance. Then test a fiber and calculate its breaking strength. The two students who are working together will have a total of four wool and six cotton fibers. Three of each kind should be tested. More have been mounted in case some of the fibers pull loose from the wire before breaking.

3. The average breaking strength of three fibers of a given kind should be recorded in a table for the entire class, preferably written on the blackboard, and the class averages should be recorded on the data sheet.

II. Threads. Test ten samples of thread. The group may consist of one sample from each of ten different spools, including various materials and sizes; or the test may include five samples from one spool and five from another, one group differing from the other in either material, size, or color. (In the latter case, values for the five samples from one spool should be averaged.)

III. Fabrics. Prepare and test lengthwise and crosswise samples of each fabric. (While a complete test consists of five lengthwise and five crosswise samples, there probably will not be time to prepare and test more than one lengthwise and one crosswise sample of each fabric.)

IV. Microscopic Examination. Observe the fibers, threads, and fabrics which have been mounted under the microscopes.

QUESTIONS:

1. Which fibers have a cellular structure?
2. Although silk is classified as an animal fiber, it is produced in an entirely different manner from wool. Explain how silk fibers are produced.
3. What do you know about the manufacture of rayon fibers?
4. Is a tightly twisted thread stronger than a loosely twisted one? Why?

[1] Specifications of the American Society for Testing Materials.

5. Do long fibers tend to make stronger threads? Why?
6. Other factors being equal, what kind of weave will produce the strongest fabric?
7. How does breaking strength differ from tensile strength?
8. If other kinds of cotton and wool fibers were tested, might the breaking strengths be quite different from those found in the laboratory?
9. How is Hooke's law illustrated in this experiment?
10. What is meant by the force constant of a Jolly balance?
11. In testing fibers, threads, and fabrics, is the force exerted parallel to the length of the sample?
12. Why should the fabric samples be cut wider and then raveled on each edge until of the desired width?
13. Which is probably stronger, men's handkerchief linen or women's handkerchief linen? Why?
14. Why is it advisable to mount more cotton fibers than wool fibers?
15. Why is it advisable to make a class average for the breaking strength of fibers, even though such an average is not made for threads and fabrics.
16. Why should the samples of a fabric be so chosen that the same yarns are not included in any two of the five samples?

Experiment 4

Name________________________

BREAKING STRENGTH OF TEXTILE MATERIALS

Location________________________

Date________________________

I. Breaking Strength of Fibers

Force constant of Jolly balance spring = ______ gm. ÷ ______ cm. = ______ gm. per cm.

Kind of Fiber	Starting Point	Breaking Point	Stretch of Spring	Force Constant of Spring	Breaking Strength of the Fiber	Average Breaking Strength	Class Average

II. Breaking Strength of Threads

Kind of Thread	Breaking Strength	Kind of Thread	Breaking Strength

III. Breaking Strength of Fabrics

Kind of Fabric	Breaking Strength

Experiment 5

MOMENTS OF FORCE AND SIMPLE MACHINES

PURPOSE: To test the laws of simple machines.

APPARATUS: Meter bar, clamp, support, two weight holders, weights, foot ruler, inclined plane, Hall's carriage, pulleys, several simple machines, such as a nutcracker, potato ricer, shears, can opener, food grinder.

THEORY: A **simple machine** is a device for transferring energy. A force (F_a) is applied to one part of the machine, and another force (F_r) is exerted by the machine against the resisting force. The resisting force may be either larger or smaller than the applied force—in general, it is larger—but this does not mean that the work done by the machine is greater than the work done on the machine, for the larger force always acts through the smaller distance. **The fundamental principle underlying all machines is that, neglecting friction, the work put into the machine is equal to the work done by the machine.**

$$F_a \times D_a = F_r \times D_r$$

where

F_a = applied force
F_r = resisting force
D_a = distance applied force moves
D_r = distance resisting force moves.

Actually the useful work done by a machine is always less than the work done on the machine, since some of the input is spent in overcoming friction. The **efficiency** of a machine is defined as the ratio of the useful work done by the machine to the work put into the machine.

$$\text{Efficiency} = \frac{F_r \times D_r}{F_a \times D_a}.$$

Since some work is always done against friction, the efficiency is always less than 100 per cent.

Lever problems may be solved by **moments of force,** or **torque.** The moment of a force, or its torque, is equal to the product of the force times the perpendicular distance from the line of action of the force to the fulcrum or point of support of the lever.

$$F_a \times L_a = F_r \times L_r$$

where

F_a = applied force
F_r = resisting force
L_a = lever arm of applied force
L_r = lever arm of resisting force.

The mechanical advantage of a machine is defined as the ratio of the resisting force to the applied force.

$$MA = \frac{F_r}{F_a}.$$

The *theoretical* mechanical advantage is obtained if the force to balance friction is not accounted for. The *actual* mechanical advantage is obtained if the force to balance friction is taken into consideration. The theoretical mechanical advantage may also be obtained by measuring the lengths of the lever arms of the machine or by measuring the distances through which the forces move.

$$MA = \frac{L_a}{L_r}$$

or

$$MA = \frac{D_a}{D_r}.$$

The numerical value of the mechanical advantage may vary from a small fraction to a large number.

Reference: Avery, pages 39–47.

PROCEDURE: *I. Moments of Force.* 1. Place the bar in the clamp, and place the clamp in the support. Slide the bar through the clamp until the position of exact balance is found, and then tighten the clamp. This bar is now supported at its center of mass. Record the reading at the knife edge bearing.

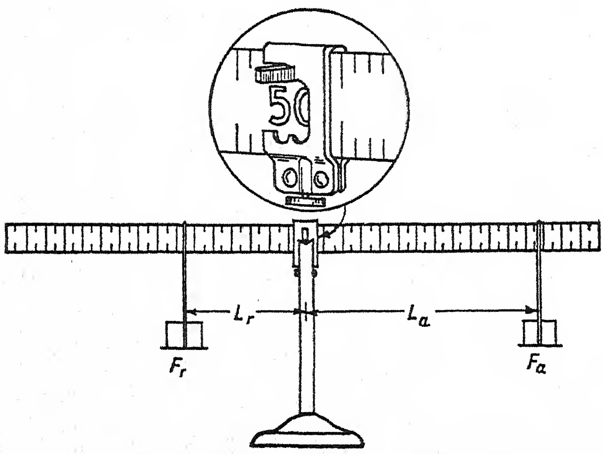


FIG. 5-a. Balancing moments of force.

2. Weigh a weight holder and place a 200-gm. mass in it. Call this total load F_r and place it on one arm of the lever at a point 20 cm. from the fulcrum (L_r = 20 cm.). Weigh a second weight holder and place a 100-gm. mass in it. Call this total load F_a. Place it on the other lever arm and shift it back and forth until an exact balance is obtained. Record the distance from the fulcrum to the point of support of F_a. This is the experimental value for L_a. From the values for F_r, L_r, and F_a, calculate the value for L_a. Compare this with the experimental value for L_a. What is the difference between the two values?

3. Remove the weight holders and shift the bar until the fulcrum is 30 cm. from one end. Place a weight holder containing a 100-gm. mass on the short arm and shift it back and forth until a perfect balance is obtained. The weight of the bar may be considered as acting at the center of mass as found above. From these data calculate the weight of the bar. Then weigh the bar on a balance. Find the error and the per cent of error in the experimental determination, using the weight obtained on the balance as the standard.

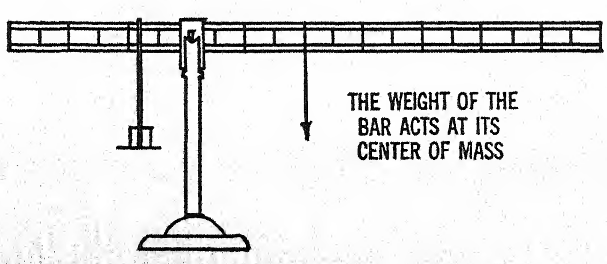


FIG. 5-b. Finding the weight of a bar by balancing moments of force.

II. Simple Machines. 1. The load which is to be used on the inclined plane is a Hall's carriage with a 1000-gm. mass in it. Weigh the carriage and record the weight of the carriage and its contents as F_r. Measure the height H and the length L of the plane. (These measurements may be marked on the inclined plane.) Place the load on the inclined plane, adjust the cord over the pulley, attach the weight holder, and add weights until the load moves with uniform velocity up the plane. Count the weights including the weight holder and record as the actual applied force. Calculate the theoretical applied force. Calculate the efficiency of the machine. Calculate the theoretical mechanical advantage from the dimensions of the machine. Calculate the actual mechanical advantage from the forces.

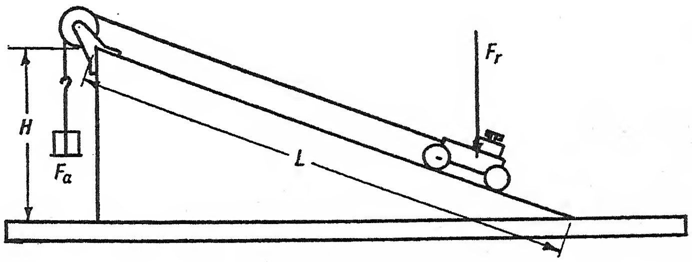


FIG. 5-c. An inclined plane.

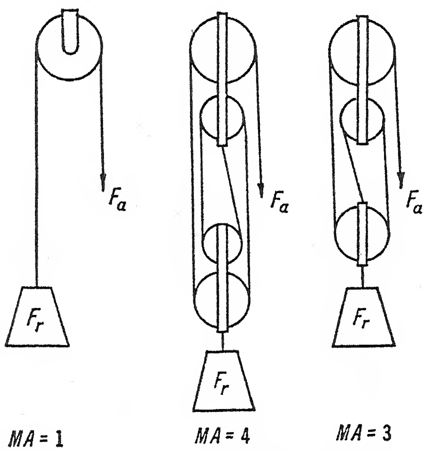


FIG. 5-d. Showing various arrangements of pulleys.

2. Use a 1000-gm. mass as the load to be lifted by the pulleys. Add weights to the free end of the cord until the resisting load F_r moves upward with uniform velocity. Count the weights and record as the actual applied force. Calculate the actual mechanical advantage. What is the theoretical mechanical advantage according to the number of cords? Knowing F_r and the theoretical mechanical advantage, calculate the theoretical applied force. (Use several arrangements of pulleys.)

3. By measurement of the lever arms, find the theoretical mechanical advantage of several of the following machines: nutcracker, shears, potato ricer, can opener, and hammer.

QUESTIONS:

1. What accounts for the difference between the theoretical and the actual work done by a machine?
2. How may friction be reduced in a machine?
3. How does the moment of a force differ from the amount of work done by a force?
4. Does the moment of a force depend on whether the machine is in motion or not?
5. Is it possible for a machine to have a large theoretical mechanical advantage and be an inefficient machine? Give an example to illustrate your answer.
6. Is it possible for a machine to have a large actual mechanical advantage and be an inefficient machine? Again give an example to illustrate your answer.
7. Does the angle at which the inclined plane rises have any effect on the force required to move the load up the plane? Explain.
8. As the number of supporting cords in a pulley system increases, does the applied force increase or decrease? Why?
9. From your data on pulleys you will note that the actual applied force increases more rapidly than the theoretical applied force. Why is this? What does it indicate about the change in efficiency of a system of pulleys as the number of supporting cords increases?
10. Is the theoretical mechanical advantage of a given machine always the same—for example, a pair of shears?

11. In general, does the efficiency of a machine depend in any way upon the mechanical advantage? Explain fully.
12. Name several devices, other than those mentioned in the text, which are applications of simple machines.
13. What force is required on the handle of a food grinder if a force of 40 pounds must be exerted on the food? The handle is 8 inches long and the average pitch of the screw is 0.75 inch.
14. If the handle of a screw driver has a diameter of 1.25 inches and the width of the blade is 0.25 inch, what force must be applied to the handle in order to exert a force of 3 pounds on the screw?
15. What is the mechanical advantage if a hammer is used to pull a nail which is 2 inches from the fulcrum and the handle is 10 inches long?
16. How many ropes must be used in a system of pulleys if a load of 200 pounds is to be lifted with an applied force of 40 pounds? Make a sketch to show the arrangement of the pulleys.

Experiment 5

MOMENTS OF FORCE AND SIMPLE MACHINES

Name____________________

Location____________________

Date____________________

I. Moments of Force

1. Center of mass = __________

2. Moments of force on a lever

   F_r = __________

   L_r = __________

   F_a = __________

   L_a = __________ (experimental)

   L_a = __________ (calculated)

   Variation in values for L_a = ________

3. Weight of meter bar

   F_r = __________

   L_r = __________

   F_a = __________ (calculated weight of bar)

   L_a = __________

   Weight of bar (by weighing on a balance) = __________

   Error = __________ − __________ = __________

   Per cent of error = ________ ÷ ________ = ________

II. Simple Machines

1. Inclined plane

   F_r = __________

   H = __________

   F_a = __________ (actual) or __________ (theoretical)

   L = __________

   Efficiency $= \frac{\text{Output}}{\text{Input}} =$ ________ = ________

   Theoretical mechanical advantage $= \frac{L}{H} =$ ________ = ________

   Actual mechanical advantage $= \frac{F_r}{F_a} =$ ________ = ________

2. Pulleys

F_r	Actual Applied Force	Actual Mechanical Advantage F_r/F_a	Number of Ropes, or Theoretical Mechanical Advantage	Theoretical Applied Force

3. Mechanical advantage (theoretical)

Machine	L_a	L_r	Mechanical Advantage

Experiment 6

VACUUM CLEANERS

PURPOSE: To study the structure of several vacuum cleaners and to make tests which will show their relative efficiencies in removing dirt from rugs.

APPARATUS: Vacuum cleaners, rugs, a supply of fine dirt,[1] equal arm balance, weights, large platform scale, wattmeter, yardstick, clock with second hand.

THEORY: In a vacuum cleaner a partial vacuum is produced by a fan which is operated by a motor. Air rushes in through the nozzle, carrying dirt and litter with it, and passes out of the machine through the dust bag, which must be made of cloth that will retain the dirt but

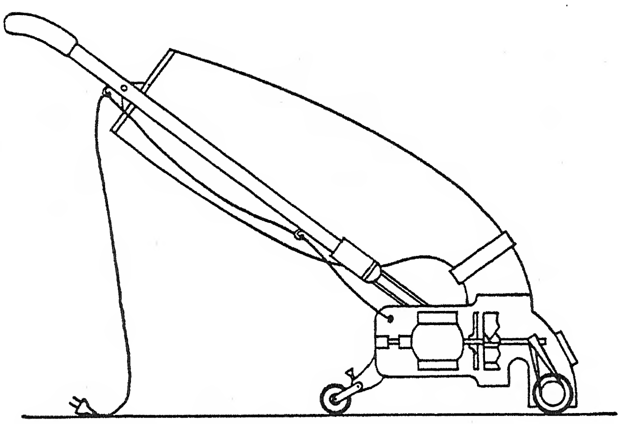


FIG. 6-a. Mechanism of a vacuum cleaner.

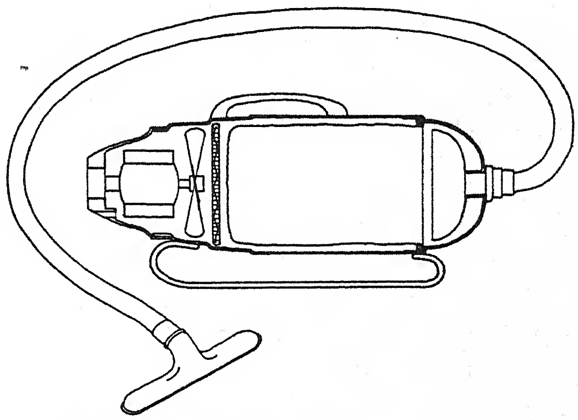


FIG. 6-b. Mechanism of a vacuum cleaner.

let the air through. Some machines have brushes and beaters which aid in removing the dirt from the rug. If a machine has a device for raising or lowering the nozzle, it should be adjusted so that the cleaner will lift the rug, causing a ripple to run along the rug as the nozzle moves over it; this opens the nap of the rug and results in more efficient cleaning. The two general types of vacuum cleaners are illustrated by the sketches in Figs. 6-a and 6-b. It is desirable to have machines of each type, as well as small cleaners for furniture and drapes, in the laboratory.

If the cleaner which is to be tested has a nozzle adjustment, it should be adjusted for the rug on which the machine is to be used, and the rug should be given a thorough preliminary cleaning. Then a predetermined amount of dirt should be worked into the nap of the rug. The rug should then be cleaned, and the per cent of dirt removed and trapped in the dust bag may be determined.

Reference: Avery, pages 72–74.

[1] See Appendix B, note on Exp. 6.

PROCEDURE: *I. Efficiency of a Vacuum Cleaner.* 1. Examine the nozzle of the cleaner to determine whether there is a brush or not, and, if so, whether it is stationary or rotating and, if rotating, whether it is driven by the motor or by the floor wheels.

2. Note the length of the nozzle, the length of the brush, and any obstructions in the nozzle, and then decide on the width of strip which the machine can clean.

3. If there is a nozzle adjustment, adjust it to the position where the cleaner lifts the rug into contact with the nozzle. Clean the rug all over thoroughly. Let the machine run for several seconds after the rug is cleaned, to carry all of the dirt away from the fan blades and into the dust bag; then tip the machine to a position such that the dirt cannot fall out of the dust bag, and turn off the current. Wait for the dust bag to collapse; then remove and empty it.

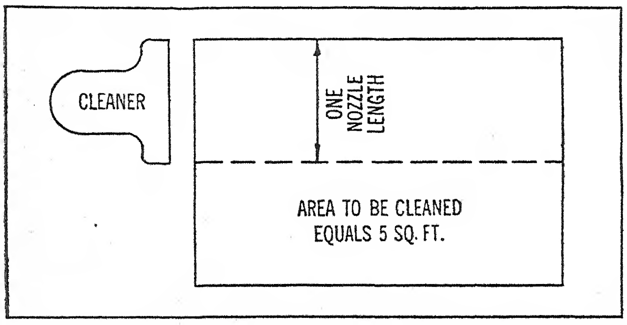


FIG. 6-c. Diagram showing the area to be used in the test.

4. Weigh the empty dust bag on the equal arm balance. (The nearest whole number of grams may be recorded for all weights in this experiment. If the data are recorded on the blackboard in a class table, each student may copy data for several additional machines.)

5. Roll up the rug and weigh it on the equal arm balance.

6. An area of 5 sq. ft. is to be used in the test. The width of the strip is to be two times the length of the nozzle. The length of the strip may be found by calculation.

7. Use 10 gm. of dirt for each square foot of rug area.[1] (10 gm. per sq. ft. $\times$ 5 sq. ft. = 50 gm. of dirt.)

8. Sprinkle the dirt over the area to be cleaned, using a large salt shaker. Distribute the dirt evenly and work it well into the nap of the rug.

9. Allow one minute for the sweeping test. This amounts to 12 sec. per sq. ft. and is equivalent to 21.6 min. for a 9 $\times$ 12 ft. rug.

10. For machines of the type shown in Fig. 6-a push the cleaner up and back the length of the strip to be cleaned in 15 sec. Make two round trips on each half of the area. This means that the cleaner goes over each part of the rug four times in a systematic manner, and at a rate slow enough that it has a chance to do thorough cleaning. For machines of the type shown in Fig. 6-b use short quick strokes, covering each part of the test area of the rug seven or eight times. Vary the angle at which the nozzle crosses the nap of the rug; since these machines do not have rotating brushes, the extra motion of the nozzle helps to agitate the nap of the rug and results in more efficient cleaning. For either type of machine let the cleaner run for several seconds after cleaning the rug and observe the precautions noted above in removing the dust bag.

11. Weigh the cleaned rug.

12. Weigh the dust bag.

13. Find the amount of dirt removed from the rug. What per cent of the dirt put on the rug has been removed?

14. Find the amount of dirt in the dust bag. What per cent of all the dirt put on the rug is in the dust bag?

[1] If any of the small cleaners for furniture or drapes are included in the test, the same general procedure may be followed, but the area to be cleaned and the amount of dirt added should be decreased. An area of 3 sq. ft. and 5 gm. of dirt per sq. ft. are suggested.

II. General Information concerning Cleaners. 1. Find the weight of the cleaner (in pounds).

2. Connect the cleaner in the wattmeter circuit and find the number of watts used by the motor.

3. Figure the cost of operating the cleaner for one hour at the local rate per K.W.H. (Since the student has not yet studied electricity in this course, the instructor will explain the method of working the problem.)

4. If possible, list the retail price of each of the cleaners used in the test.

5. Study the data for the various cleaners and study the cleaners. Decide on the good and poor points of each general type.

6. Leave the cleaner, and all of the equipment you have used, clean and in good order.

QUESTIONS:

1. List several things concerning which you would have to make some decision before purchasing a vacuum cleaner.
2. What adjustments may the operator make on a cleaner to obtain the greatest efficiency?
3. What care must a cleaner have in order that it may operate efficiently?
4. Do the two general types of cleaners have the same essential parts? How do they differ?
5. Why is one type of cleaner run slowly over a rug in a very systematic way, while the other type is moved faster and at varying angles?
6. Do you think the time allowed for the sweeping test is too short, reasonable, or too long? Why?
7. Do you think the efficiency of the cleaner may vary with the type of dirt used? Why?
8. Do you think the efficiency of the machine may depend in part on the person who operates it? Why?
9. Why is the weight of the cleaner of interest?
10. Is the variation in cost of operation enough to make the cost of operation a deciding factor in purchasing a cleaner?
11. Is the variation in retail price enough to make the retail price a deciding factor in purchasing a cleaner?
12. Discuss the good and poor points of each of the general types of vacuum cleaners.

Experiment 6

VACUUM CLEANERS

Name____________________________

Location____________________________

Date____________________________

1. Name of cleaner						
2. Type of brush						
3. Nozzle adjustment (yes or no)						
4. Weight of clean rug						
5. Weight of dirt						
6. Weight of rug + dirt						
7. Weight of rug after test						
8. Weight of dirt removed from rug						
9. Per cent of dirt removed						
10. Weight of empty bag						
11. Weight of bag + dirt						
12. Weight of dirt in bag						
13. Per cent of dirt in bag						
14. Weight of cleaner						
15. Watts used						
16. Cost of operation per hour						
17. Retail price of cleaner						

Experiment 7

THERMOMETERS

PURPOSE: To test the accuracy of a thermometer and to study various thermometers which have been made for special purposes.

APPARATUS: A Centigrade and a Fahrenheit thermometer, beaker, Bunsen burner, ice, and a selection of thermometers which have been designed for special purposes.

THEORY: A **thermometer** is a device for measuring temperatures. Most thermometers depend upon the expansion of some material to indicate the temperature; the material may be a solid, a liquid, or a gas. The two chief thermometer scales in use at the present time are the Centigrade and the Fahrenheit. The fixed points on each are the freezing and the boiling points of water; on the Centigrade scale these temperatures are 0° and 100° respectively, and on the Fahrenheit scale, 32° and 212° respectively. (These temperatures are for standard barometric pressure.) The following formulas give the relationships between the two scales:

$$C. = \tfrac{5}{9}\,(F. - 32)$$
$$F. = \tfrac{9}{5}\,C. + 32$$

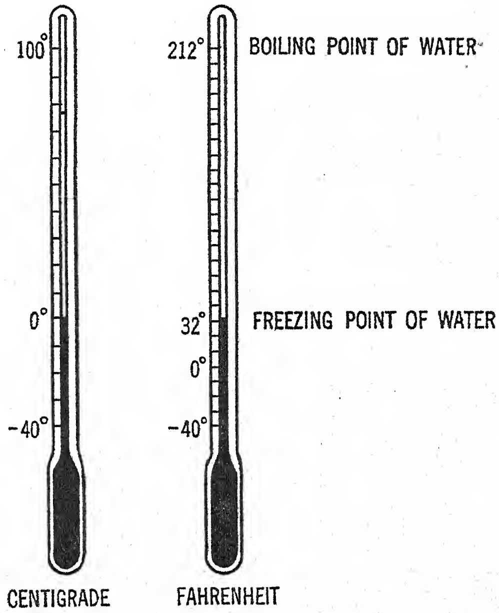


FIG. 7-a. Thermometer scales.

The accuracy of a thermometer depends chiefly upon the care exercised in its construction and calibration. A thermometer must be reasonably accurate to be of much value, and the better grades of thermometers are usually quite accurate, but the less expensive grades are often very inaccurate. The quickness of response of a thermometer to a given temperature is often important. This depends upon the shape of the thermometer and the material of which it is made. In general, the greater the surface area of the expanding medium, the better the thermometer's response. A thermometer which has large intervals on the scale for each degree is said to be more sensitive than one which has small intervals.

Reference: Avery, pages 102–114.

PROCEDURE: *I. Accuracy of a Thermometer.* 1. Test the accuracy of the freezing point on each of two thermometers, one of good grade and one which is less expensive. (It is suggested that one of these thermometers be a Fahrenheit ranging from about −20° to 120°, and the other a Centigrade ranging from −20° to 110°.) Suspend the two thermometers in a beaker of finely chipped ice for at least ten minutes. Stir the ice occasionally and be sure the ther-

mometer bulbs do not touch the beaker. Record the temperature each should read, and the temperature each does read.

2. Of the two thermometers used above, test the less expensive one for accuracy by comparing it with the better thermometer for at least six points on its scale. These readings should be spaced about five degrees apart on the Centigrade scale or about ten degrees apart on the Fahrenheit scale. To do this suspend the two thermometers in a beaker of ice-cold water, adjusting them so that the bulbs do not touch the glass; then place the beaker over a Bunsen burner flame. When the temperature has gone up approximately the required number of degrees, remove the burner, stir the water thoroughly, and wait until the reading on each thermometer becomes stationary before recording a set of data. Replace the burner and repeat the procedure the required number of times. If you have used a Centigrade and a Fahrenheit thermometer, change the readings of the better thermometer to the corresponding readings for the other scale, and calculate the errors for the less expensive thermometer.

II. Thermometers for Special Purposes. 1. Study the following household thermometers, noting whether the scale is Centigrade or Fahrenheit, the range, and any unusual features.

Oven thermometer
Meat thermometer
Jelly and candy thermometer
Fat thermometer
Refrigerator thermometer
Dairy thermometer
Clinical thermometer
Bath thermometer

2. Study the following group of thermometers, noting whether the scale is Centigrade or Fahrenheit, the range, the purpose, and any unusual features.

Maximum thermometer
Minimum thermometer
Combination maximum and minimum thermometer
Thermograph

QUESTIONS:

1. What liquids were used in these thermometers? What solids were used?
2. What factors enter into the accuracy of a thermometer?
3. Explain how it is possible for a thermometer to be accurate at the freezing and the boiling points of water but inaccurate at points between, and sometimes reading too high and again too low.
4. What factors affect the quickness of response of a thermometer?
5. Name some thermometers in which quickness of response is important.
6. What determines the sensitiveness of a thermometer?
7. What are the two chief thermometer scales in use at the present time? Does either have any advantages over the other?
8. Name several possible failures in cooking which might be eliminated if a thermometer were used.
9. What is the purpose of a constriction in the bore of a thermometer?
10. Why is the maximum thermometer mounted so that it will lie nearly horizontal, but with the bulb end slightly higher?
11. How is the maximum thermometer reset?
12. How does surface tension enter into the operation of a minimum thermometer? What causes surface tension?
13. Why is the minimum thermometer mounted in a horizontal position?
14. How is the minimum thermometer reset?
15. What causes the markers in the combination maximum and minimum thermometer to move upward?

16. Why do the markers in the combination maximum and minimum thermometer always remain at the highest positions to which they have been moved?
17. Which ends of the markers in the combination maximum and minimum thermometer indicate the maximum and the minimum temperatures?
18. How is the combination maximum and minimum thermometer reset?
19. What causes the motion of the cylinder on which the thermograph chart is mounted?
20. Why are the lines on the thermograph chart, which indicate hours, curved instead of straight?

Experiment 7

THERMOMETERS

Name____________________

Location____________________

Date____________________

I. Accuracy of a Thermometer

1. Accuracy of freezing point

   Centigrade thermometer should read _____; does read _____; error _____

   Fahrenheit thermometer should read _____; does read _____; error _____

2. Accuracy at temperatures above the freezing point

C.	F.	___ TO ___	ERROR

II. Thermometers for Special Purposes

1. Household thermometers

NAME	SCALE	RANGE	SPECIAL FEATURES

2. Maximum, minimum, and recording thermometers

NAME	SCALE	RANGE	SPECIAL FEATURES

Experiment 8

CHANGE OF STATE

PURPOSE: To determine the heat of fusion and the heat of vaporization for water.

APPARATUS: Calorimeter, equal arm balance, weights, thermometer, Bunsen burner, ice, steam generator, water trap.

THEORY: The **heat of fusion** of a material is the number of heat units required to change the state of a unit mass of the material from a solid to a liquid when it is at its change-of-state temperature. The **heat of vaporization** of a material is the number of heat units required to change the state of a unit mass of the material from a liquid to a vapor when it is at its change-of-state temperature. When a solid is changed to a liquid, or when a liquid is changed to a vapor, heat is absorbed by the material which is undergoing a change of state; but when a liquid is changed to a solid, or when a vapor is changed to a liquid, heat is given out by the material which is undergoing a change of state. Under like conditions the amount of heat which is absorbed in a given change is equal to the amount of heat given out when the reverse change takes place. Changes in atmospheric pressure have a negligible effect on the freezing point of water, but the boiling point varies appreciably with barometric changes.

If ice is added to warm water in a calorimeter, the water and the calorimeter will be cooled, and the heat lost by them will be equal to that required to melt the ice and to warm the resulting water to the final temperature of the mixture. In a like manner, if steam is added to water in a calorimeter, the water and calorimeter will be warmed, and the heat gained by them will be equal to that given out by the steam in condensing plus that given out by the water formed by the steam as it attains the final temperature of the mixture.

Reference: Avery, pages 130–133.

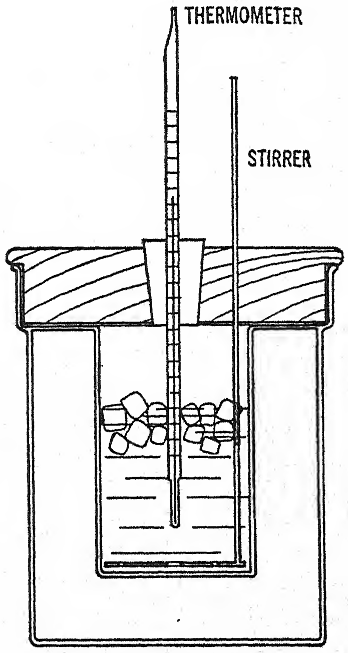


FIG. 8-a. Heat of fusion apparatus.

PROCEDURE: *I. Heat of Fusion.* 1. Weigh the inner calorimeter cup and stirrer. Fill the cup half full of water at a temperature about ten Centigrade degrees above the temperature of the room. Weigh again and determine the mass of the water. Place the cup in the outer calorimeter vessel, put on the cover, and insert a thermometer.

2. Obtain a supply of ice which has been broken into small pieces. Place the pieces on a towel or in a funnel so they will drain, thus keeping the ice more or less dry. (Small ice cubes from a mechanical refrigerator are convenient since their flat surfaces are easily dried. The cubes should be frozen slowly; otherwise there will be small water pockets in the cubes.)

3. Stir the water in the calorimeter, and record the exact temperature. Add pieces of ice, drying each piece with a towel before it is added. Be careful not to splash the water. Keep stirring the water and adding ice until the temperature is about ten Centigrade degrees below the temperature of the room. When all of the ice is melted, record the lowest temperature obtained.

4. Weigh the inner calorimeter cup and contents. The gain in weight is equal to the mass of the melted ice.

5. Solve for the heat of fusion of ice. (The specific heat of the calorimeter cup is stamped on it, or will be furnished by the instructor.)

6. Compare your answer with the value given in the text. Find the error and the per cent of error in your determination of the heat of fusion for ice.

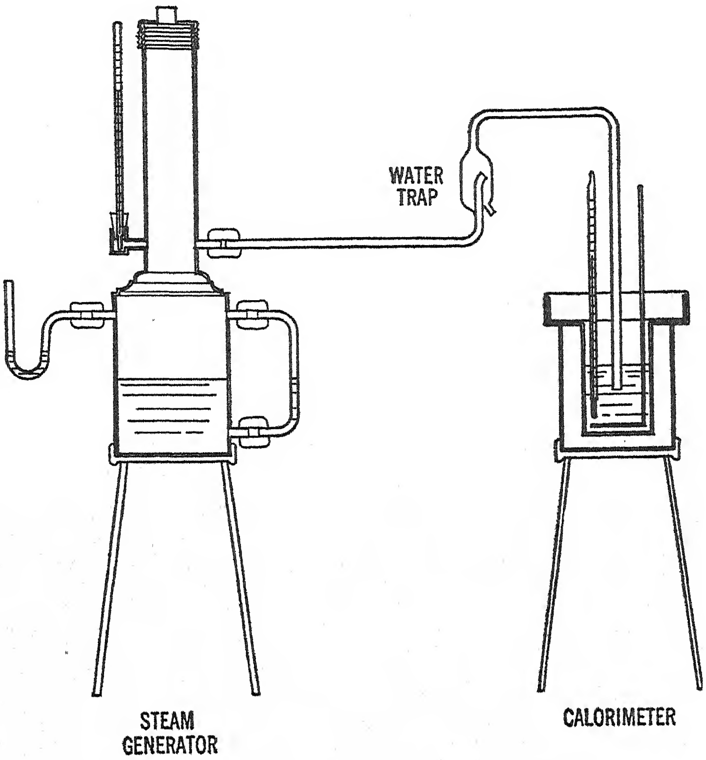


FIG. 8-b. Heat of vaporization apparatus.

II. Heat of Vaporization. 1. Fill the steam generator about half full of water, put on the cover, and place it over the burner.

2. Use the same calorimeter that was used in the first part of the experiment. Fill the inner cup about two-thirds full of water at a temperature about ten Centigrade degrees below the temperature of the room. Weigh again and determine the mass of the water. Place the cup in the outer calorimeter vessel, put on the cover, and insert a thermometer.

3. As soon as the steam is issuing from the delivery tube of the steam generator in a steady stream, attach the water trap which will catch any condensed steam. Place a wooden screen between the steam generator and the calorimeter.

4. Stir the water in the calorimeter and record the exact temperature. Immediately thereafter put the short delivery tube from the water trap into the calorimeter, so that the end of the tube is about 3 cm. below the surface of the water. Continue to stir the water until the temperature is about ten Centigrade degrees above the temperature of the room. Remove the delivery tube, stir the water until the temperature remains constant, and record this temperature.

5. Weigh the inner calorimeter cup and contents. The gain in weight is equal to the mass of the condensed steam.

6. Record the barometer reading [1] and determine the corresponding boiling point for water from the table in the *Handbook of Chemistry and Physics.*

7. Solve for the heat of vaporization for steam.

8. Compare your answer with the value given in the text. Find the error and the per cent of error in your determination of the heat of vaporization for steam.

[1] See Appendix A for directions for reading the barometer.

QUESTIONS:

1. Why is a double walled calorimeter used in these experiments?
2. Why is the temperature change varied from a given number of degrees above room temperature to an equal number of degrees below room temperature (or vice versa)?
3. Why must the pieces of ice be dried before they are placed in the calorimeter?
4. Why must the steam generator be covered?
5. Why is a water trap used?
6. Could there be any condensation between the water trap and the calorimeter? Why should the delivery tube be as short as possible?
7. Why is it necessary to determine the boiling point of water before solving for the heat of vaporization?
8. Is the heat of vaporization for water at 98° C. higher or lower than at 100° C.? Why?
9. Is any error made in not accounting for the heat involved in the change of temperature of the thermometer?
10. Calculate the heat of fusion for ice in B.T.U. per pound, using the value given in the text for heat of fusion in calories per gram.
11. How much heat is absorbed when 100 pounds of ice melts?
12. If ice at −10° C. had been used in the experiment, how would the equation for heat exchanges have differed from the one you set up?
13. How much steam would be required to heat one kilogram of water from 20° to 50° C. in a container which weighs 100 grams and has a specific heat of 0.22?
14. The units for heat of fusion and heat of vaporization are calories per gram and B.T.U. per pound. Why are they not calories per gram per degree C. and B.T.U. per pound per degree F.?

Experiment 8

CHANGE OF STATE

Name______________________________

Location____________________________

Date_______________________________

I. Heat of Fusion

Mass of calorimeter cup and stirrer	
Mass of calorimeter cup, stirrer, and warm water	
Mass of warm water	
Temperature of warm water (just before adding ice)	
Temperature of cooled water (after all of the ice is melted)	
Mass of calorimeter cup, stirrer, water, and melted ice	
Mass of ice	
Change in temperature of warm water and calorimeter	
Change in temperature of the water formed by the melted ice	
Specific heat of the calorimeter cup and stirrer	
Heat of fusion of ice (experimental)	
Heat of fusion of ice (standard)	
Error	
Per cent of error	

II. Heat of Vaporization

Mass of calorimeter cup and stirrer	
Mass of calorimeter cup, stirrer, and cool water	
Mass of cool water	
Temperature of cool water (just before adding steam)	
Temperature of warmed water (after adding steam)	
Mass of calorimeter cup, stirrer, water, and condensed steam	
Mass of steam	
Barometer reading	
Corresponding boiling point for water	
Change in temperature of cool water and calorimeter	
Change in temperature of the water formed by the condensed steam	
Specific heat of calorimeter cup and stirrer	
Heat of vaporization of steam (experimental)	
Heat of vaporization of steam (standard)	
Error	
Per cent of error	

Experiment 9

FREEZING AND BOILING POINTS OF SOLUTIONS

PURPOSE: To study the effect of solutes on the freezing and boiling points of water.

APPARATUS: Calorimeter, thermometer, ice, salt, sugar, small beaker, wooden spatula, test tube, balance, weights.

THEORY: In general, when a solid is dissolved in a liquid, the material which is dissolved is the **solute,** the liquid is the **solvent,** and the combination is a **solution.** Pure water freezes at 0° C. or 32° F. (standard atmospheric pressure) and in freezing it gives out heat; ice normally melts at the same temperature and absorbs heat in the process. If some solute, such as salt or sugar, is dissolved in water, its freezing point is lowered. A smaller mass of salt than of sugar is required for a given temperature drop.[1]

Also the melting point of ice is lowered if some solute is present because there is an attraction between the molecules of the solute and the molecules of the ice which decreases the energy required to melt the ice. As the ice melts, it absorbs heat from the solution and thus lowers the temperature of the solution, but the temperature can be lowered only to the freezing point of the solution. Smaller masses of salt than of sugar are required for a given decrease in the melting point.[2]

The use of common salt (NaCl) with ice in freezing ice cream is an example of obtaining a lower temperature by this means. The ice cream mixture must be cooled to about −8° C. or 17° F. in order to harden. A mixture of salt and ice will produce this low temperature, but ice alone will not harden the ice cream. If a ratio of about one part of salt to six or eight parts of ice is used, the ice cream will be smoother than if more salt is used, because rapid freezing produces larger crystals in the ice cream. A ratio of one part of salt to three or four parts of ice will produce the lowest temperature that can be obtained with these materials. Salts other than NaCl will produce still lower temperatures, but in general they are more expensive to use.

When any crystalline solid dissolves in a liquid, there is always a change in the temperature of the solvent. As a rule the temperature falls, indicating that heat has been absorbed, but some crystals cause the temperature of the solution to rise. The heat absorbed or evolved by one gram of the solid in dissolving is called the **heat of solution.**

Pure water boils at 100° C. or 212° F. (standard atmospheric pressure), but when some solute,

[1] The lowering of the freezing point of a given weight of a solvent produced by a gram-molecular weight of any nonelectrolyte (for example, sugar) is the same because the decrease depends on the numerical ratio between the number of molecules of the solute and the number of molecules of the solvent. A gram-molecular weight of any nonelectrolyte dissolved in 1000 c.c. of water lowers the freezing point approximately 1.87° C. A gram-molecular weight of an electrolyte (for example, salt) dissolved in the same volume of water lowers the freezing point almost twice as much since most of the molecules break up into two ions, each of which has the same effect as a molecule. The exact amount the freezing point is lowered depends on the degree of ionization. Since the molecular weight of sugar (cane) is 342 and that of salt is 58, a given mass of salt will contain many more molecules than an equal mass of sugar, and in addition the molecules of salt ionize, thus further increasing the effect of the salt.

[2] As the amount of solute is increased, the ratio of the number of molecules (or ions) of solute to the number of molecules of solvent is increased, and the attraction between the two increases as this ratio increases.

such as salt or sugar, is dissolved in it, the boiling point is raised, the increase depending upon the kind and amount of the solute. The water boils at a higher temperature because the solute decreases the vapor pressure of the solution and the solution has to be heated to a higher temperature before the vapor pressure exceeds the atmospheric pressure. As at the freezing point, smaller masses of salt than of sugar are required for a given temperature increase.[1]

In making candies or syrups the temperature of the solution at the boiling point is used as a means of determining the concentration of the solution. When vegetables, fruits, meat, etc., are boiled in water, some of their contents dissolve in the water, and the boiling point is increased slightly above normal.

Reference: Avery, pages 133–134 and 137–138.

PROCEDURE: ***I. Effect of a Solute on the Freezing Point of Water.*** 1. Place some finely chipped ice in the inner cup of a calorimeter. Insert a thermometer and a small test tube containing enough water to cover the bulb of the thermometer. When the thermometer in the ice has reached the lowest temperature to which it will go, record what it should read, what it does read, and the error. Then place the thermometer in the water in the test tube. Wait until it goes no lower and record the temperature. Note whether the water in the test tube freezes or not.

2. Weigh out five quantities of salt of 10 gm. each. (Sugar may be used instead of salt.) Weigh the empty calorimeter and add 100 gm. of finely chipped ice. Insert the thermometer and add the salt to the ice in 10 gm. quantities. Keep the ice and salt well stirred with a wooden spatula and record the lowest temperature caused by each addition.

3. Wash the thermometer and put it in the test tube containing water which was used in the first part of the experiment. Put the test tube in the salt and ice mixture. Note if the water freezes and record the lowest temperature reached by the thermometer. (Run tap water on the test tube to melt the ice surrounding the thermometer.)

II. Effect of a Solute on Water at Normal Temperatures. Obtain a supply of salt and a supply of water having the same temperature. Put 50 c.c. of water in a small beaker, insert the thermometer, and note the reading carefully. Then add 15 gm. of salt and note the temperature change. Decide on the reason for this temperature change.

III. Effect of a Solute on the Boiling Point of Water. 1. Record the barometer reading [2] and determine the corresponding boiling point for water from the table in the *Handbook of Chemistry and Physics.*

2. Put 100 gm. (100 c.c.) of water in a covered beaker. Heat the water until it boils and record the temperature of the boiling water and of the steam. (The thermometer may be inserted through the hole in the cover.)

3. Add 15 gm. of salt to the above water, and heat the solution until it boils. Record the temperature of the boiling solution and of the steam. (Be very sure there is no salt on the bulb of the thermometer when recording steam temperatures.)

4. Add another 15 gm. of salt to the above solution, and heat it until it boils. Record the temperature of the boiling water and of the steam.

[1] The decrease in vapor pressure depends on the numerical ratio between the number of molecules or ions of the solute and the number of molecules of the solvent. A gram-molecular weight of any nonelectrolyte (for example, sugar) dissolved in 1000 c.c. of water raises the boiling point approximately 0.52° C. A gram-molecular weight of an electrolyte (for example, salt) dissolved in the same volume of water increases the boiling point approximately 1° C.

[2] See Appendix A for directions for reading the barometer.

QUESTIONS:

1. Why should the ice which is used in the first part of the experiment be finely chipped?
2. Why doesn't the water in the test tube freeze when it is placed in the ice?
3. Why does a mixture of salt and ice result in a lowering of the temperature?
4. What ratio of salt to ice causes the lowest temperature?
5. Is the ratio noted in question 4 ideal for freezing ice cream? Why?
6. Why does the water in the test tube freeze when it is placed in the salt and ice mixture?
7. What is heat of solution?
8. Why is it important in this experiment to know the boiling point corresponding to the barometric pressure?
9. Why does salt increase the boiling point of water?
10. What are the freezing and the boiling points of a saturated salt solution? Of a saturated sugar solution? (Consult the *Handbook of Chemistry and Physics*.)
11. Why does a given mass of salt produce a greater change in the freezing or the boiling point of a solution than does the same mass of sugar?
12. Why is NaCl generally used in freezing mixtures instead of some other salt? Name several other salts which will produce low temperatures when mixed with ice, and if possible, record the lowest temperature which may be obtained in each case.

Experiment 9

Name____________________

Location____________________

Date____________________

FREEZING AND BOILING POINTS OF SOLUTIONS

I. Effect of a Solute on the Freezing Point of Water

1. Thermometer in ice should read ______; does read ______; error ______
   Thermometer in water in test tube in ice reads ______
   Water in test tube (does, does not) freeze
2. Effect of adding salt to ice

Temperature of ice	0° C.
Temperature of ice plus 10 gm. salt	
Temperature of ice plus 20 gm. salt	
Temperature of ice plus 30 gm. salt	
Temperature of ice plus 40 gm. salt	
Temperature of ice plus 50 gm. salt	

3. Thermometer in water in test tube in salt-ice mixture reads ______
   Water in test tube (does, does not) freeze

II. Effect of a Solute on Water at Normal Temperatures

Temperature of water (50 c.c.)	
Temperature of salt (15 gm.)	
Temperature of water after salt is added	
Decrease in temperature of water	

III. Effect of a Solute on the Boiling Point of Water

1. Barometer reads ______; corresponding boiling point is ______
2. Water boils at ______; steam temperature is ______
3. Water (100 gm.) + salt (15 gm.) boils at ______; steam temperature is ______
4. Water (100 gm.) + salt (30 gm.) boils at ______; steam temperature is ______

Experiment 10

PRESSURE COOKERS AND PRESSURE-TEMPERATURE CURVES FOR WATER VAPOR

PURPOSE: To determine the effect of pressure on the boiling point of water and to become familiar with the use of the pressure cooker.

APPARATUS: A pressure cooker to which a thermometer has been added, a pressure cooker instruction book, a gas plate, small quantities of foods such as meat, potatoes, rice, beans, macaroni, and apples.

THEORY: When water is boiled in an open dish, its temperature rises to the boiling point and remains constant at a temperature which depends chiefly upon the atmospheric pressure. But **when water is boiled in a closed vessel, the temperature at which it boils is found to increase as the pressure increases,** and while the change in temperature is not directly proportional to the change in pressure, the change is always in the same general direction. This has made possible the pressure cooker, which is used for cooking foods in a shorter time than they can be cooked at the normal boiling temperature of water, and for processing canned meats and vegetables. It is also used in high altitudes where the normal boiling point of water is too low for cooking some foods.

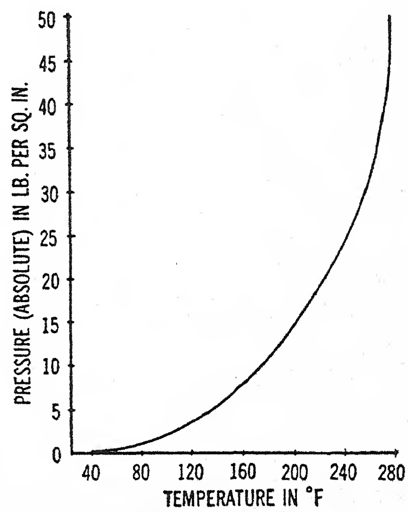


FIG. 10-a. Pressure-temperature curve for water vapor.

A pressure cooker is usually made of cast aluminum with a close fitting lid which can be tightened to form a steam-tight joint with the body of the cooker. The lid is equipped with a pressure gauge, a petcock, and a safety valve. The pressure gauge registers the pressure in pounds per square inch over and above normal atmospheric pressure. The petcock is an outlet for air or steam, or an inlet for air as the case may be. The safety valve, as its name suggests, is a device which will allow steam to escape before the pressure reaches a dangerous amount. The petcock and the safety valve may be combined into one attachment. The cookers in the laboratory differ from those sold commercially in that they also have thermometers mounted on the lids so that pressure-temperature data may be recorded.

Reference: Avery, pages 68, 137–138, and 140–142, and the pressure cooker instruction book.

PROCEDURE: *I. Effect of Pressure on Temperature.* 1. Study the instruction book which is furnished with your cooker. It gives a detailed description of the cooker and its attachments, and instructions for its use. Be sure you understand each part.

2. Place about $1\frac{1}{2}$ pints of water in the cooker, fasten the lid on according to the directions in the instruction book, be sure the petcock is open, and place the cooker over the lighted gas plate.

3. Record the barometer reading [1] and determine the corresponding boiling point for water from the table in the *Handbook of Chemistry and Physics.*

4. When the steam has been escaping in a steady stream for at least three minutes (to insure driving out all of the air), and when the thermometer has reached the boiling point indicated by the barometer reading, turn the fire low and close the petcock. Record pressures and temperatures for each change of 2 lb. per sq. in. from 0 to 26 lb. per sq. in. Tap the gauge gently while data are being recorded so that the pointer of the pressure gauge will move gradually rather than jerkily. It will probably be necessary to turn the gas flame a little higher as the cooker heats to higher temperatures.

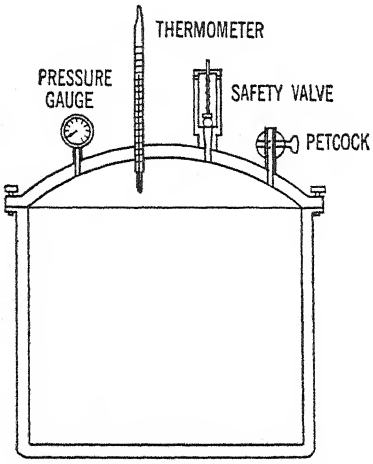


FIG. 10-b. Cross section of a pressure cooker.

5. Open the petcock slowly and let the pressure go down to zero. Then remove the lid of the cooker.

6. Plot a pressure-temperature curve [2] on coordinate paper, plotting gauge pressures on the y-axis and temperatures on the x-axis.

7. From the *Handbook of Chemistry and Physics* obtain data for a standard pressure-temperature curve, for a temperature range from 100° to 135° C. or from 212° to 275° F. If these data are given in absolute pressures, change them to gauge pressures before plotting. (Absolute pressures are changed to the corresponding gauge pressures by subtracting the pressure of the atmosphere.) Plot this curve on the same sheet as the experimental curve.

*II. **Cooking Food in a Pressure Cooker.*** 1. Cook the food assigned to you by the instructor. The cooking of the various foods should be started so that all will be finished at the same time. The instructor will announce the time at which the food should be ready to serve and will advise the student as to the length of the cooking period and the pressure to be used. When the food is cooked arrange it in a dish and place it on the serving table.

2. Wash and dry all dishes, silver, and cooking utensils.

QUESTIONS:

1. Why does increasing the pressure over a liquid raise the boiling point?
2. Why should the air be driven from the cooker before the petcock is closed?
3. Why must the pressure be down to atmospheric pressure before the lid is loosened?
4. Should the petcock be opened as soon as the food is cooked or after the pressure has gone down to atmospheric pressure? Might this depend on the kind of food? Give examples.
5. If the pressure has been allowed to go down to atmospheric pressure or less with the petcock closed, can the lid be removed before the petcock is opened? Why?
6. When should one begin to time the cooking if one is using a pressure cooker—when the petcock is closed, or when the pressure has reached the amount designated in the recipe book?
7. When one is canning in glass cans with a pressure cooker, the pressure should be allowed to go down to zero on the gauge with the petcock closed. Why? Why are the cans sometimes only partly filled with liquid when removed from the cooker?
8. When one is canning in tin cans with a pressure cooker, why may the petcock be opened as soon as the cooking time has elapsed? Why do the ends of the tin cans bulge when they are removed from the cooker but not after they have cooled?
9. Give rules to be observed in caring for the cooker and its attachments.

[1] See Appendix A for directions for reading the barometer.

[2] See Appendix A for directions for plotting a curve.

Experiment 10

Name________________________

PRESSURE COOKERS AND PRESSURE-TEMPERATURE CURVES FOR WATER VAPOR

Location________________________

Date________________________

Effect of Pressure on Temperature

1. Barometer reads ________; corresponding boiling point is ________
2. Data for experimental curve

Gauge Pressure	Temperature
0 lb. per sq. in.	
2	
4	
6	
8	
10	
12	
14	
16	
18	
20	
22	
24	
26	

3. Data for standard curve from *Handbook of Chemistry and Physics*

Temperature	Absolute Pressure	Gauge Pressure

Experiment 11

FUELS

PURPOSE: To determine the amount of heat energy which may be liberated by a fuel when it is burned.

APPARATUS: Parr calorimeter assembly, analytical balance and weights, samples of dried and powdered fuels such as coal, wood, sugar, and flour,[1] gas calorimeter, gas meter, Bunsen burner, source of running water at constant pressure and temperature, two thermometers, balance, weights, small gas stove, a selection of kitchen kettles.

THEORY: The fuel value of a solid may be determined by using a Parr calorimeter in which the heat liberated by the fuel is absorbed by the metal parts of the calorimeter and the water which is placed in it. Given amounts of the fuel, potassium perchlorate, and sodium peroxide are placed in the bomb which is then sealed and placed on a stand in the calorimeter vessel which has previously had two liters of water placed in it. The calorimeter vessel is contained in a well-insulated, double-walled jacket, and covered with an insulated lid. The fuel is ignited by sending a current of electricity through a fuse wire which is attached to the lid of the bomb. A uniform final temperature is insured by rotating the bomb which is fitted with vanes to stir the water.

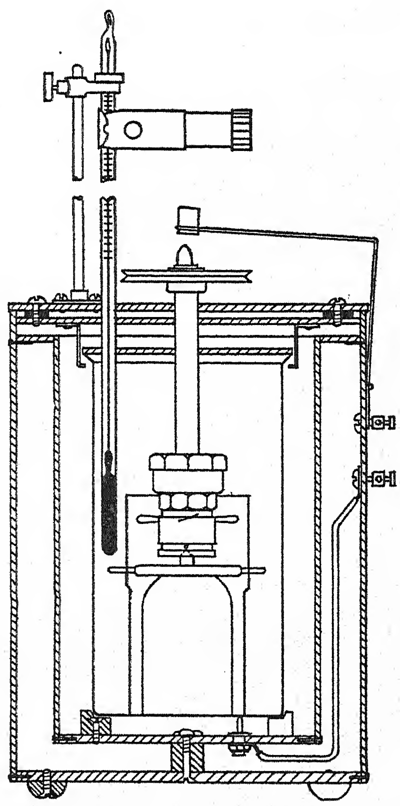


FIG. 11-a. Cross section of a Parr calorimeter.

The fuel value of a gas may be determined experimentally by use of a gas calorimeter in which the heat developed during oxidation of the gas is used to raise the temperature of the calorimeter and its contents. The gas is passed through a gas meter and burned in a Bunsen burner, *C*, in the gas calorimeter, which consists of a double-walled vessel with a central cavity. The cavity is open at the bottom so that a gas burner may be inserted. The water enters the calorimeter at the bottom and leaves at the top, and is warmed by the heat which is conducted through the inner wall from the gas flame. For best results this water should come from a supply, *A*, which maintains a constant pressure and temperature. The inlet temperature is taken at T_i, and the outlet temperature at T_o. The water is collected at *D*, and weighed. The heat which is absorbed by the calorimeter does not enter into the calculations because the calorimeter is allowed to heat until steady temperature conditions exist before any data are recorded.

[1] A Parr oxygen calorimeter is recommended for foods if extreme accuracy is of prime interest. However, the peroxide calorimeter gives satisfactory results.

The combined efficiency of a given gas burner and kettle may be determined by measuring the amount of gas used in heating the kettle and a given amount of water, noting the resulting temperature change, and calculating the amount of heat delivered to the water.

Reference: Avery, pages 144–152, and the instruction books furnished with the calorimeters.

PROCEDURE: *I. Fuel Value of Solid Fuels.* 1. Weigh the water container, the stand, and all of the pieces of the bomb. These parts have a specific heat of approximately 0.1.

2. Set the bomb aside, place the water container and stand in the calorimeter jacket, and pour two liters of water into the vessel. The temperature of this water should be approximately one Centigrade degree below that of the room.

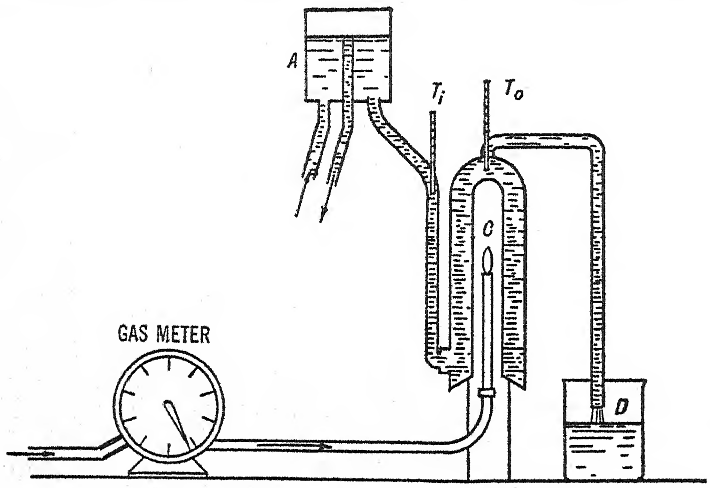


FIG. 11-b. Cross section of a gas calorimeter.

3. Use an analytical balance[1] and weigh out one-half gram of the fuel to be tested. Place the fuel in the fusion cup of the bomb, and cover it immediately with the false cover to keep out moisture.

4. Weigh one gram of potassium perchlorate ($KClO_4$) on the analytical balance. Mash any lumps which may be in it and place it in the fusion cup. Put on the false cover and shake thoroughly for at least one minute.

5. Add one measure (10 c.c.) of sodium peroxide (Na_2O_2) to the mixture in the fusion cup, and again mix the materials by shaking.

6. Attach a fuse wire to the stem cover. Place this cover on the fusion cup and put the cup in the bell body. Be sure the bearing depression in the floating bottom is on the lower side where it will ride on the pivot bearing of the stand. Tighten the cap of the bomb with a wrench until it is water tight, and attach the spring clips with the blades downward and so placed that the holes in the bell body are unobstructed. Care should be taken not to tip the bomb and thus get the fuel mixture on the electrodes of the lid. (**All of these operations should be checked by the instructor.**)

7. Place the bomb in the water container, put on the insulated cover, and insert the thermometer. Place the pulley wheel on the top of the stem cover which extends through the insulated lid, and put the belt from the stirring motor in place. Start the motor and adjust its speed so that the bomb will turn at about 150 revolutions per minute.

8. When the thermometer reaches a constant reading, record this temperature and close the switch in the firing circuit. The lamps which are included in this circuit will light briefly until the fuse wire melts. Open the firing switch and watch the thermometer for the highest temperature which occurs. Record this highest temperature.

9. Open the calorimeter, pour out the water, and dry the pieces of the bomb. The fusion cup may be placed in water in a glass or porcelain dish, where the residue will dissolve. The electrodes on the stem cover should be washed and cleaned carefully and the remaining pieces of wire removed.

[1] See Appendix A for directions for using an analytical balance.

10. Compute the amount of heat added to the water and the metal parts of the calorimeter. Only 73 per cent of this heat came from the fuel; the other 27 per cent came from the chemicals which were mixed with the fuel and from the oxidation of the fuse wire.

11. Determine the fuel value of the material tested in terms of B.T.U. per pound for coal or wood, or in kilo-calories per gram for any of the foods.

II. Fuel Value of a Gas. 1. Adjust the water connections so that water will enter A rapidly enough to cause an overflow through the tube provided for that purpose. The water entering the calorimeter will then be at a constant pressure. The temperature of the water should be about five Centigrade degrees below room temperature. Arrange to collect the water which has passed through the calorimeter, at D.

2. Turn on the gas, light the burner, and adjust the gas flow and the air valve until the flame is not more than two inches high and of good color.[1] This is to insure complete combustion of the gas and to burn the gas slowly enough that all of the heat may be absorbed by the water. Be sure the water is flowing through the calorimeter as it should and then insert the burner in the central cavity. Let the calorimeter heat until the thermometer reading at T_o is constant. The flow of the water should be adjusted so that T_o is approximately as much above room temperature as T_i is below room temperature.

3. When the temperature difference remains reasonably steady, collect the water which passes through the calorimeter during the time in which 0.1 cu. ft. (or 0.5 cu. ft.) of gas is being burned. Record the temperatures at T_i and T_o as each 0.01 cu. ft. is burned. Average the values for each if any variation has occurred.

4. Turn off the gas; then turn off the water. Determine the mass of the water collected, either by weighing or by measuring it.

5. Calculate the number of B.T.U. per cubic foot. Compare this value with the known fuel value for the gas which has been tested.

III. Efficiency of a Given Gas Burner and Kettle. 1. Weigh an empty kettle, with or without the lid as instructed; then put about two quarts of water in it and weigh again. Find the mass of the water. Record a brief description of the kettle as to material and size, and state whether it is covered or uncovered.

2. Connect the gas cock to the gas meter and the gas meter to the gas burner. Light the burner.

3. Determine the temperature of the water in the kettle, and when the pointer on the gas meter dial is exactly over a graduation mark, place the kettle over the burner.

4. When the water in the kettle has reached a temperature of 80° to 90° C. and when the pointer on the gas meter dial is exactly over a graduation mark, turn off the gas and record the highest temperature reached by the water. This highest temperature may occur a little after the gas has been turned off.

5. Record the number of cubic feet of gas burned.

6. Calculate the quantities asked for on the data sheet.

QUESTIONS:

1. What is a fuel?
2. What are the chief chemical compounds found in fuels?
3. Why is information concerning fuel values of importance?

[1] When the ratio of gas to air is properly adjusted, the gas flame consists of two cones, an inner blue-green one and an outer purple one. There should be no red or orange flame, as this indicates incomplete combustion due to lack of sufficient oxygen.

Parr calorimeter

4. Why is it important that all of the materials, which are placed in the bomb, be finely powdered?
5. Why are the potassium perchlorate and the sodium peroxide added to the fuel in the bomb?
6. Why is it important that the bomb be water-tight?
7. Why should the rate of rotation of the bomb not be too great?
8. Do you know any reason why the fuel value of coal is expressed in B.T.U. per pound, while that of sugar is given in kilo-calories per gram?
9. If the number of calories per gram of fuel is known, the number of B.T.U. per pound may be found from B.T.U. per lb. $= \frac{9}{5} \times$ cal. per gm. Explain why this is possible.

Gas calorimeter

10. Why is the water equivalent of the calorimeter not considered in the calculations for the fuel value of a gas?
11. Why should the inlet temperature of the water be below room temperature and the outlet temperature an equal amount above room temperature?
12. Why should the water enter from a source at constant pressure?

Efficiency of gas burners

13. How is a gas stove burner similar to a Bunsen burner?
14. What adjustments may be made on the gas stove burner to make it more efficient?
15. How may the shape and material of the kettle affect the combined efficiency of the burner and kettle?
16. Will covering the kettle influence the efficiency?
17. What will it cost to heat a gallon of water (8.3 lb.) from 70° to 212° F. if gas costs $0.50 per thousand cubic feet and the combined efficiency of the burner and kettle is 40 per cent?
18. What will it cost to heat 50 gallons of water from 70° to 170° F. if the gas costs $0.50 per thousand cubic feet and the tank heater is 50 per cent efficient?

Experiment 11

Name ____________________

FUELS

Location ____________________

Date ____________________

I. Fuel Value of a Solid

Kind of fuel		
Mass of metal parts of calorimeter		
Specific heat of metal parts of calorimeter		
Mass of water		
Temperature of water before fuel is burned		
Temperature of water after fuel is burned		
Heat gained by water and metal parts from ____ gm. of fuel		
Fuel value (experimental)		
Fuel value (as listed in fuel tables)		

II. Fuel Value of a Gas

Kind of gas		
Mass of water and container		
Mass of container		
Mass of water		
Average T_i		
Average T_o		
Temperature change		
Volume of gas burned		
Fuel value (experimental)		
Accepted local fuel value of gas		

III. Combined Efficiency of a Gas Burner and Kettle

Description of kettle used		
Mass of kettle		
Mass of kettle and water		
Mass of water		
Specific heat of kettle		
Temperature of water before heating		
Temperature of water after heating		
Temperature change		
Number of cubic feet of gas used		
Number of calories of heat added to water		
Number of calories of heat added to kettle		
Number of calories of heat furnished by gas		
Per cent of heat delivered to water		
Per cent of heat delivered to kettle		
Per cent of heat delivered to water and kettle		
Cost of gas used at $______ per thousand		

Experiment 12

INSULATING PROPERTIES OF BUILDING MATERIALS

PURPOSE: To determine the relative rates at which heat is conducted through various building materials.

APPARATUS: Conductivity box, heating coil, samples of insulating materials (2 ft. square), rheostat, wattmeter, two thermometers, clock.

THEORY: **Conduction** is the method of heat transfer by which energy is transmitted from molecule to molecule in a material medium. The **coefficient of conductivity** of a material is defined (in metric units) as the number of calories transferred per second through an area of one square centimeter, if the temperature difference between the two surfaces is one Centigrade degree and the length of the path is one centimeter. The amount of heat transferred by conduction may be determined by

$$H = \frac{KA(t_1 - t_2)T}{L}$$

where

H = heat in calories
K = coefficient of conductivity
A = area in sq. cm. through which heat is conducted
t_1 = temperature of hot surface in degrees Centigrade
t_2 = temperature of cold surface in degrees Centigrade
T = time in seconds
L = length of path in centimeters.

It is a well-known fact that some materials conduct heat much better than others. Most of the materials which are used in the construction of the walls of buildings are relatively poor conductors of heat. Thus the interior of the building is kept cooler in the summer and warmer in the winter. In recent years a great variety of insulating materials have been placed on the market. These differ widely in composition, thickness, method of installing, and cost. This experiment is intended to show the relative rates at which heat is conducted through some of these materials when placed under identical conditions. It is advisable to test the samples at a thickness used in practice. Then curves may be plotted which will show the relative insulating values of the materials.

The apparatus used in this experiment consists of a wooden box, 2 × 2 × 3 ft., which is cut in two at the mid-point of the 3-foot dimension, and has the cut edges covered with felt. The box is lined with a 3-inch layer of rock wool. The lower half contains a socket for an electric heating coil; a wattmeter and a rheostat are connected in the circuit which supplies energy to this coil. The wattmeter makes it possible to know the rate at which energy is being furnished, and the rheostat makes it possible to hold the energy input rate constant. The layer of insulating material is fitted between the two halves of the box. The upper half of the box has a thermometer inserted through the center of the top surface, with the bulb of the thermometer at

about the center of the upper compartment. The heat from the electric heating coil is conducted through the layer of insulating material and warms the air in the upper compartment. The slower the rate at which the temperature rises in the upper compartment, the better are the insulating properties of the material being tested.

Reference: Avery, pages 156–157.

PROCEDURE: ***Relative Insulating Properties of Building Materials.*** 1. Connect the heating coil, the rheostat, and the ammeter terminals of the wattmeter in series with the terminals of the service wires. Connect the voltmeter terminals of the wattmeter across the heating coil. (Since the student has not yet studied electricity in this course, the instructor will assist in wiring the circuit and will explain the operation of the rheostat.) All of the heating coils in the experiment will be operated at the same wattage, and the room temperature will be held as nearly constant as possible during the test.

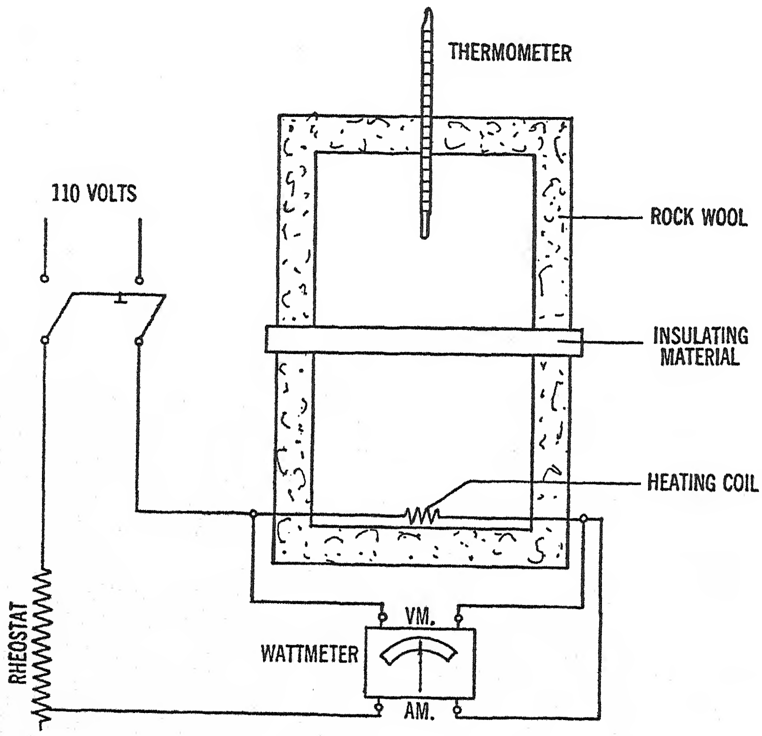


FIG. 12-a. Apparatus for determining the relative insulating values of building materials.

2. Record the room temperature at the beginning of the test, and at 15-minute intervals during the test.

3. Record the reading of the thermometer in the top of the box at the beginning of the test, and at 15-minute intervals throughout the test. Keep the wattmeter reading constant by adjusting the rheostat.

4. Plot curves[1] for several of the materials used in the experiment, plotting time on the x-axis and temperatures on the y-axis. Number the curves and indicate the names of the materials in a legend. The data for room temperatures should be plotted to give a curve for comparison. Under ideal conditions, this curve will be a straight line parallel to the x-axis.

QUESTIONS:

1. Why is it preferable to test the insulating properties of these materials at thicknesses used in practice rather than using the same thickness for each material?
2. Why is it important to keep a record of the room temperature?
3. Which is more important, to insulate the roof or to insulate the side walls of a house?
4. Does the insulating ability increase directly with the thickness of the material in actual installations of insulation in houses?
5. What precautions must be observed to get the full benefit of insulation materials in the walls and roof?

[1] See Appendix A for directions for plotting a curve.

Experiment 12

Name________________________

INSULATING PROPERTIES OF BUILDING MATERIALS

Location________________________

Date________________________

Watts used by heating coil = __________

Time	Room Temperature	Temperature of Thermometer in Top of Box					
		Glass	Pine Board				

Experiment 13

MOISTURE CONTENT OF THE ATMOSPHERE

PURPOSE: To study methods of measuring the moisture content of the atmosphere.

APPARATUS: Bright-surfaced beaker, thermometer, ice, salt, wet and dry bulb thermometers (stationary and sling), Hygrodeik, hygrograph, Humidiguide, hair hygrometer, electric fan.

THEORY: **Absolute humidity** is the mass of water vapor contained in a unit volume of the atmosphere. **Relative humidity** is the ratio of the amount of moisture which is in the atmosphere to the amount required for saturation at that temperature. **Dew point** is the temperature at which the atmosphere becomes saturated if it is cooled. In this experiment absolute humidity will be expressed in grains per cubic foot, relative humidity in per cent, and dew point in degrees Fahrenheit. At a temperature of 65° to 70° F., the most healthful relative humidity is from 40 to 50 per cent.

If a given surface is cooled below the dew point of the atmosphere, moisture will collect on it; the dew which forms on a glass containing a cold drink is an example of this. The highest temperature at which the dew just begins to form is the dew point temperature.

If water evaporates from a wick placed around the bulb of a thermometer, the thermometer will be cooled and will read less than a thermometer in the same region which has no evaporation taking place around its bulb; thus the depression of the wet bulb thermometer is an indication of the amount of moisture in the atmosphere. Since the space immediately around the wet bulb tends to become saturated, it is necessary that these thermometers be placed in a moving stream of air. The readings of the two thermometers may be used with suitable tables to find the relative humidity and the dew point. A Hygrodeik consists of a set of wet and dry bulb thermometers and a chart which has been plotted from the data in the relative humidity and dew point tables.

Hairs and strips of cellulose are known to increase in length as the relative humidity of the atmosphere increases. Hygrometers in which these changes in length are used to indicate the relative humidity are direct-reading instruments; the fibers are connected to a pointer which swings over a scale whenever the fiber changes length. If the pointer is equipped with a pen which records the relative humidity on a chart, the device is known as a hygrograph.

Reference: Avery, pages 190–201.

PROCEDURE: *I. Dew Point Method.* 1. Find the dew point by filling a bright-surfaced metal beaker about half full of water and adding small pieces of ice until the first trace of dew appears on the sides of the beaker. Be careful not to breathe on the beaker, to touch it with the hands, or to spill any water on the outside of it. (If dew has not appeared when the temperature of the water in the beaker has reached 32° F., add a little salt and more ice; continue until dew does appear.) Then stir the water and watch for the dew to disappear. Repeat this process several times and use the average value for the dew point temperature.

2. Using the room temperature, the dew point temperature, and the table showing the amount of water vapor required for saturation at various temperatures, find the absolute humidity and the relative humidity.

II. Wet and Dry Bulb Thermometers. 1. Read one set of wet and dry bulb thermometers. The stationary set should be placed in front of the electric fan or fanned by hand until the wet bulb reading goes no lower. The sling hygrometer should be swung according to the directions with the instrument until the wet bulb reading goes no lower. Using the wet and dry bulb tables, find the relative humidity and the dew point. (One set of wet and dry bulb thermometers has a calibrated cylinder with directions for reading the relative humidity directly from the cylinder.)

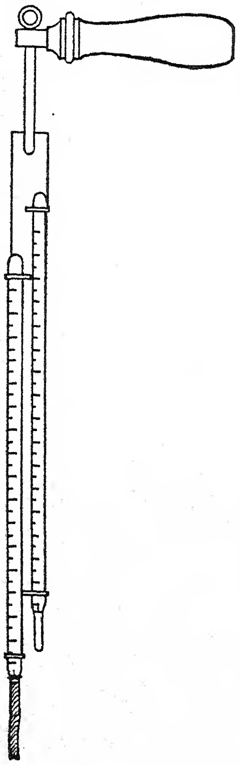


FIG. 13-a. A sling hygrometer.

2. Follow the directions given on the Hygrodeik and determine the relative humidity, the absolute humidity, and the dew point.

III. Direct-reading Hygrometers. 1. Examine the hygrograph to see how it operates. How may the tension on the hairs be adjusted? Record the relative humidity indicated by it.

2. Examine the Humidiguide to see how it operates. How may the tension on the cellulose strip be adjusted? Record the relative humidity indicated by it.

3. Examine the hair hygrometer in the round case to see how it operates. How may the tension on the hair be adjusted? Record the indicated relative humidity.

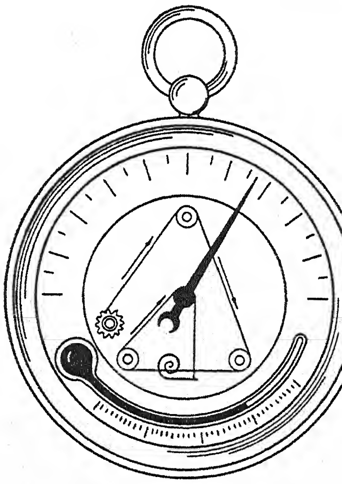


FIG. 13-b. A hair hygrometer.

QUESTIONS:

1. Does the amount of moisture required for saturation increase as the temperature increases? Does it increase at a constant rate?
2. Which has the lower reading—the wet or the dry bulb thermometer? Why?
3. Under what condition will the wet and dry bulb thermometers show large differences? Under what condition will they read the same?
4. Why should the air about the wet and dry bulb thermometers be in motion?
5. Will the relative humidity indicators which depend upon the change of length of a hair or a cellulose strip respond to changes more or less quickly than the wet and dry bulb instruments? Why?
6. Will the tension on the cellulose strips probably need adjustment if the instrument is used under decidedly different temperature conditions? Why?
7. Where would hygrograph records be of value?
8. Of the various instruments studied for determining relative humidity, which do you prefer for your home? Why?
9. Where have you noticed relative humidity indicators in use?
10. If the absolute humidity at noon is 4.526 gr. per cu. ft. at a temperature of 65° F. and that night the temperature drops to 40° F., what will probably result? If the temperature drops to 20° F., what will probably result?
11. Is it correct to say that heating the air dries it? Which is lowered—the absolute or the relative humid-

ity? Will the answer to this question depend in part upon whether or not the air is allowed to expand as it is heated?

12. Why are cold water pipes and other cold surfaces more likely to "sweat" in summer than in winter?
13. What is the effect of low relative humidity on the respiratory organs? On the general feeling of comfort of a person? On furniture and floors?
14. Why is a high relative humidity in the summer so uncomfortable?
15. Why do you see a cloud of moisture coming from your mouth and nose on cold days?
16. As a room fills with people, will the relative humidity increase or decrease? Why?
17. What determines whether the water vapor in the atmosphere will appear as dew or frost?
18. Some papers and fabrics which are to be preserved for long periods of time are kept in constant temperature, constant humidity rooms. Explain how either too high or too low relative humidities or temperatures might harm the materials.
19. Suggest methods for increasing the relative humidity in a house which is heated with a hot air furnace. If the house is heated with a hot water or a steam furnace, how may the relative humidity be increased?
20. If air is cooled by forcing it through a spray of water, what is the effect on the relative humidity? Is this a desirable condition in the summer time?
21. Calculate the mass of water vapor which must be evaporated to increase the relative humidity of a room from 20 to 50 per cent if the temperature is 68° F. The room is $12 \times 20 \times 8$ ft.

Experiment 13

MOISTURE CONTENT OF THE ATMOSPHERE

Name____________________________

Location____________________________

Date____________________________

I. Dew Point Method

1. Bright beaker method

Dew point	Dew appeared				
	Dew disappeared				
Absolute humidity					
Room temperature					
Amount of moisture required for saturation					
Relative humidity					

II. Wet and Dry Bulb Thermometers

1. ____________________ with tables
(Indicate which set of wet and dry bulb thermometers was used.)

Dry bulb	
Wet bulb	
Depression of wet bulb	
Relative humidity	
Dew point	

2. Hygrodeik

Dry bulb	
Wet bulb	
Relative humidity	
Absolute humidity	
Dew point	

III. Direct-reading Hygrometers

1. Hygrograph. Relative humidity at _____ (hour) _____ (day)	
2. Humidiguide. Relative humidity	
3. Hair hygrometer. Relative humidity	

Experiment 14

HOUSEHOLD MOTORS

PURPOSE: To calculate the cost of operation and the horsepower output for various household motor-driven appliances.

APPARATUS: Ammeters, voltmeters, wattmeters, sockets, household motor-driven appliances (fan, sewing machine, vacuum cleaner, refrigerator, kitchen mixer, clock), source of 110-volt AC current.

THEORY: A **motor** is a device which transforms electrical energy into mechanical energy. When a current of electricity is sent through a motor, two magnetic fields result—one in the armature coils and one in the field coils. Reaction between these two magnetic fields causes the armature to rotate. In general, the number of watts used by an electrical device may be found by

$$W = I_a E_v$$

where

W = power in watts
I_a = current intensity in amperes
E_v = potential difference in volts.

However, because of various factors (the type of current used, the manner in which the armature and field coils are wound and connected, the speed of the motor, and the amount of iron included in the armature and field), the actual number of watts used by a motor is usually less than the number indicated by the ammeter and voltmeter readings. A wattmeter gives the actual number of watts used. The ratio between the actual watts used and the number indicated by the ammeter-voltmeter method is known as the **power factor**. If the power factor is known, the actual number of watts used may be calculated by

$$\text{Watts} = I_a E_v \times \text{power factor.}$$

The number of watts used by a motor changes as the load is varied. Most household motors operate at constant load, but the effect of changing the load may be observed by watching the reading of the wattmeter as the load is increased or decreased. As the load is increased, the motor slows down and the number of watts required increases.

The cost of using an electric motor depends upon the number of watts used, the length of time it is used, and the rate per K.W.H.

$$\text{Cost} = \frac{\text{watts}}{1000} \times T_h \times \text{rate per K.W.H.}$$

The output of a motor is usually rated in terms of horsepower and 1 H.P. is equivalent to 746 watts. If the efficiency of a motor is known, its horsepower may be found by

$$\text{H.P. output} = \frac{\text{watts}}{746} \times \text{efficiency.}$$

A small plate is usually attached to the appliance on which is stated the voltage, the type of current (AC, DC, or either; if AC, the number of cycles), and either the number of watts or the current required. Sometimes other information is given, such as the revolutions per minute, the serial number of the motor, and the name of the company that made the motor. This plate should be studied before connecting a motor to a circuit, to avoid accidents or injury to the motor.

Reference: Avery, pages 240–247.

PROCEDURE: *I. Ammeter-Voltmeter Method.* 1. Connect the motor-driven appliance, the ammeter, and the terminals of the service wires in series; connect the voltmeter in parallel with the appliance. *Have your connections checked by the instructor.*

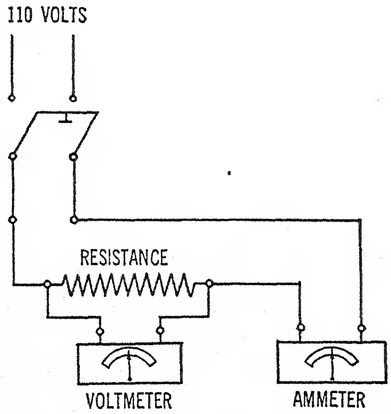


FIG. 14-a. Wiring diagram showing use of ammeter and voltmeter.

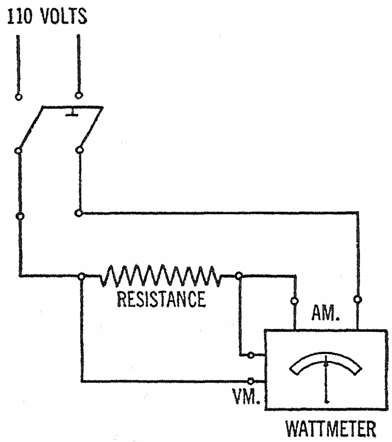


FIG. 14-b. Wiring diagram showing use of wattmeter.

2. Record the ammeter and voltmeter readings for each appliance after the motor has reached its normal speed. Calculate the number of watts as indicated by these meter readings.

II. Wattmeter Method. 1. Use a wattmeter in the circuit instead of the ammeter and voltmeter. Connect the ammeter terminals of the wattmeter in series with the appliance and the voltmeter terminals in parallel with the appliance. *Have your connections checked by the instructor.*

2. Record the wattmeter reading for each appliance after the motor has reached its normal speed. Using the wattmeter reading and the local rate per K.W.H. calculate the cost per hour for operating each of the motor-driven appliances. Calculate the watt output and the H.P. output of the motor assuming that the efficiency is 70 per cent.[1]

III. Effect of Increase of Load. Put water or a very thin batter in the bowl of the kitchen mixer and start the motor (on high). Record the wattmeter reading. Then use a very thick batter and record the meter reading.

IV. Mechanism of a Motor. 1. Take apart a small household motor, learn the names of the various parts, note the electrical connections, clean any parts that need cleaning, reassemble the motor, oil it, and test it to see that it is working properly.

2. Repeat, using another type of motor.

3. Examine the mechanisms of two electric clocks—one of the type which has to be "started"

[1] This is merely an assumed efficiency and does not mean that all household motors operate with an efficiency of 70 per cent; however, 70 per cent may be a fair average for small motors.

after it is connected to the line and one which is "self-starting." The motor in an electric clock is a synchronous motor. The instructor will explain how a synchronous motor operates.

QUESTIONS:

1. Why is the ammeter wired in series with the load?
2. Why is the voltmeter wired in parallel with the load?
3. Explain how the wattmeter is wired in the circuit.
4. Which gives the actual number of watts used—the product of the ammeter and voltmeter readings, or the wattmeter reading?
5. Can the cost of operating a motor-driven appliance be estimated before the appliance is purchased?
6. What will it cost to use the kitchen mixer to mix one cake [1] if the time required is 10 minutes?
7. What will it cost to use the refrigerator for one month on the assumption that the motor operates 10 hours in each 24 hours?
8. What will it cost to run the fan on high speed for 8 hours?
9. How long can the sewing machine be operated for $0.01?
10. What will it cost to operate the clock for one year?
11. What will it cost to clean a 9 × 12 ft. rug if 20 minutes is allowed for a thorough cleaning?
12. How does the watt input of a motor vary as the load on the motor increases? How does this affect the cost of operating the motor?
13. Why do some electric clocks have to be "started" after they are connected to the line? How does a "self-starting" clock differ from one which has to be started?
14. Will an electric clock keep accurate time if the number of cycles per second varies?

[1] Use the local rate per K.W.H. in all cost problems.

Experiment 14

HOUSEHOLD MOTORS

Name______________________________

Location____________________________

Date_______________________________

Appliance	I_a	E_v	Power in Watts		Cost per Hour at \$____ per K.W.H.	Watt Output if 70% Efficient	H.P. Output
			Calculated	Wattmeter			

Effect of Increase of Load

Kitchen mixer—thin batter—uses ________ watts.

Kitchen mixer—thick batter—uses ________ watts.

Experiment 15

THE HEAT EQUIVALENT OF ELECTRICAL ENERGY

PURPOSE: To determine the number of watt-seconds equivalent to one calorie, or conversely, the number of calories equivalent to one watt-second.

APPARATUS: Calorimeter, electrical heating coil, ammeter, voltmeter, rheostat, a 110-volt source of electrical energy (either AC or DC), equal-arm balance, weights, thermometer.

THEORY: When a current of electricity is sent through a conductor, the electrical energy may be transformed into heat energy; the electrical energy may be measured in watt-seconds and the heat energy in calories. It has been found by experiment that 4.186 watt-seconds of electrical energy are equivalent to one calorie of heat energy, or that 0.24 calorie is equivalent to one watt-second.

$$H = \frac{I_a E_v T_s}{4.186} \text{ or } 0.24\, I_a E_v T_s$$

where
H = heat in calories
I_a = current in amperes
E_v = potential difference in volts
T_s = time in seconds.

In this experiment one measures the transformed electrical energy by measuring the heat gained by a certain amount of water and by the container in which the water is placed. A well-insulated calorimeter should be used. The temperature of the water at the beginning of the experiment should be as many degrees below room temperature as the temperature at the end of the experiment is above room temperature, to avoid errors due to gains or losses of heat between the calorimeter and its surroundings. The potential difference applied to the heating coil and the current through it may be controlled by means of a rheostat; consequently the voltmeter and ammeter readings may be held practically constant. Since the coil gives up its energy rather slowly, better results are obtained with a relatively small current. The water should be stirred constantly during the experiment to insure a uniform final temperature.

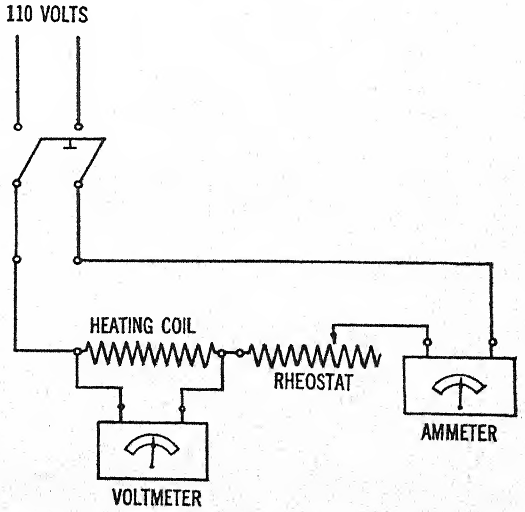


FIG. 15-a. Wiring diagram of apparatus used in finding the heat equivalent of electrical energy.

Reference: Avery, pages 250–251.

PROCEDURE: ***Transformation of Electrical Energy into Heat Energy.*** 1. Weigh the metal calorimeter cup. Add enough water to cover the heating coil, and weigh again. (The tempera-

ture of the water should be several degrees below room temperature.) Determine the mass of the water.

2. Connect the heating coil, rheostat, and ammeter in series with the terminals of the service wires. Connect the voltmeter in parallel with the heating coil.

3. Place the heating coil in the water in the calorimeter. Insert the thermometer, adjusting its position until the bulb is at a point about half-way down in the water.

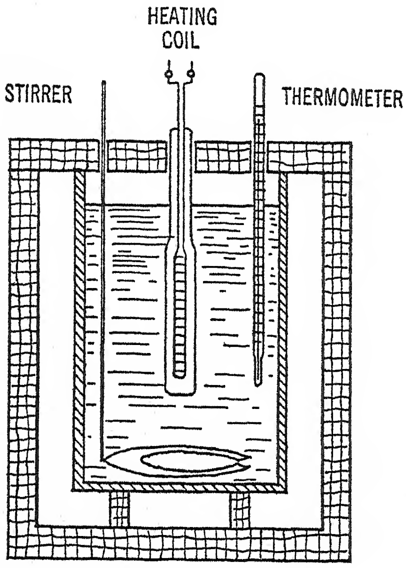


FIG. 15-b. Cross section of a calorimeter.

4. Close the switch and adjust the resistance of the rheostat until the potential difference across the coil is about 40–50 volts. Record the ammeter and voltmeter readings.

5. Open the switch and stir the water until the thermometer reaches a constant temperature. Read this temperature very carefully and record.

6. Note the time and close the switch. Keep the water stirred and adjust the rheostat, if necessary, to keep the ammeter readings constant. When the temperature of the water is about as much above room temperature as the beginning temperature was below room temperature, open the switch but keep on stirring the water until the temperature goes no higher. Read this temperature carefully and record.

7. Calculate the number of calories of heat added to the calorimeter cup and its contents. The specific heat of the calorimeter cup will be stamped on the cup, or will be furnished by the instructor. The water equivalent of the heating coil and stirrer will be furnished by the instructor.

8. From the elapsed time and the meter readings, calculate the number of watt-seconds of energy used by the heating coil.

9. Determine the number of watt-seconds equivalent to one calorie, and the number of calories equivalent to one watt-second.

10. Compare your values with the standard values and find the error and the per cent of error.

QUESTIONS:

1. Why is it important to have a well-insulated calorimeter?
2. Why should the water be below room temperature at the beginning of the experiment and an equal amount above room temperature at the end?
3. Why should the water entirely cover the heating coil?
4. Why may the position of the thermometer bulb in the water influence its reading?
5. Which is the larger amount of energy—a watt-second or a calorie?
6. How many calories of heat will be generated if a 1000-watt heater is used for 20 minutes?
7. If a heater must furnish 1000 calories per minute, what current will be required at 110 volts?

Experiment 15

THE HEAT EQUIVALENT OF ELECTRICAL ENERGY

Name________________________

Location________________________

Date________________________

Mass of calorimeter cup	
Mass of calorimeter cup + water	
Mass of water	
Specific heat of calorimeter cup	
Water equivalent of heating coil and stirrer	
Temperature at beginning of experiment	
Temperature at end of experiment	
Temperature change	
Time when current is turned on	
Time when current is turned off	
Time current is allowed to flow (in seconds)	
Ammeter reading	
Voltmeter reading	
Heat added to calorimeter cup and contents	
Watt-seconds of energy used by heating coil	
Watt-seconds per calorie	
Calories per watt-second	
Error (for one answer only)	
Per cent of error	

Experiment 16

ELECTRICAL HEATING APPLIANCES

PURPOSE: To calculate the cost of operation and the number of calories of heat developed in a given time by various electrical heating appliances.

APPARATUS: A 110-volt source of electrical energy (preferably AC), ammeters, voltmeters, wattmeters, sockets, heating appliances, water, coffee, bread, and eggs.

THEORY: When a current of electricity is sent through an electrical heating device, the electrical energy is transformed into heat energy. The amount of heat energy, which may be

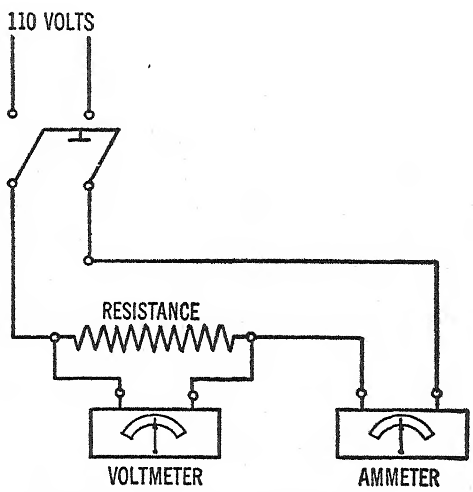


FIG. 16-a. Wiring diagram showing the use of ammeter and voltmeter.

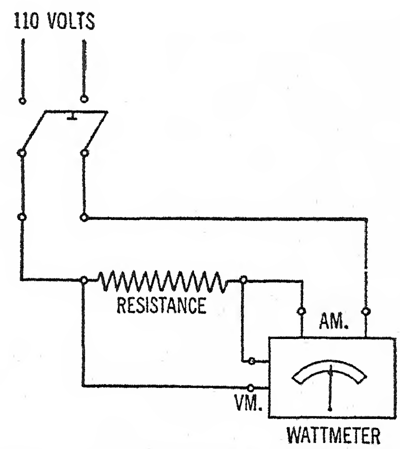


FIG. 16-b. Wiring diagram showing the use of wattmeter.

measured in watt-seconds, is determined by the rate at which electrical energy is used and the time during which it is used. After the number of watt-seconds of energy has been determined the equivalent number of calories may be calculated, since 4.186 watt-seconds equal one calorie or one watt-second equals 0.24 calorie. The cost of operating an electrical device is determined by the rate at which electrical energy is used, the time during which it is used, and the cost per K.W.H.

Not all of the heat developed by an electrical heating appliance is useful. In the case of a cooking appliance, some escapes into the air and some is used to heat the appliance rather than the food. In the case of a flatiron, some is used to heat the iron and some escapes into the air; the useful heat is that transmitted to the damp clothes. The ratio of the useful heat to the total amount of heat developed is the efficiency of the appliance.

Reference: Avery, pages 249–269.

PROCEDURE: *I. Study of Appliances Which Are Often Used for Long Periods of Time.* 1. Included in this group are lamps, heating pads, irons, hot plates, radiators, and electric ranges. Connect the electrical heating appliance, the ammeter, and the terminals of the service wires in series; connect the voltmeter in parallel with the heating appliance. If a wattmeter is used, connect the ammeter terminals in series with the heating appliance and the voltmeter terminals in parallel with the heating appliance.

2. Record the meter readings for each of the appliances listed, and make the calculations which are indicated on the data sheet. If a wattmeter has been used, the approximate current may be found by dividing the wattmeter reading by the known voltage of the line. Use the local rate per K.W.H. in the cost problems.

3. Study the range elements to find how either three or five degrees of heat are possible with only two heating coils.

4. Study the oven elements to find how they are connected for preheating, baking, and broiling.

5. Find how the oven temperature control operates.

II. Study of Appliances Which Are Generally Used for Short Periods of Time. Connect the circuits as in Part I, record the necessary data, and work several of the following problems. Use the local rate per K.W.H.

a. Find the cost of making one slice of toast.
b. Find the cost of making four servings of coffee.
c. Find the cost of cooking one waffle.
d. Find the cost of toasting one sandwich.
e. Find the cost of cooking four eggs.
f. Find the cost of warming one 8-oz. bottle of milk.

III. Efficiency of an Electrical Heating Appliance. Find the efficiency of (a) one of the coffee makers, or (b) the combined efficiency of one of the range hot plates and a given pan. To do this, heat a suitable mass of water from room temperature to 90° C., and calculate the number of calories of heat gained by the water. Note the time of heating, the ammeter and voltmeter readings, and from these compute the electrical energy used.

QUESTIONS:

1. How does the cost per hour for operating a 100-watt lamp compare with that for operating a 50-watt lamp?
2. How do you explain the fact that the ammeter connected with the iron reads the same whether the iron is turned to high, medium, or low heat?
3. If the heat indicator on the iron is turned to "high," is the iron using electrical energy all of the time?
4. Does the ammeter connected with the heating pad read the same whether the pad is turned on high, medium, or low heat? Explain why.
5. Explain how the hot plate elements of a range are connected for three degrees of heat.
6. Explain how the hot plate elements of a range are connected for five degrees of heat.
7. Explain how the oven elements are connected for preheating, baking, and broiling.
8. Explain how the oven temperature control operates.
9. Will there be a difference in the cost of making a slice of toast, depending upon whether it is the first slice or one made after the toaster is hot?
10. Will it cost more to make six servings of coffee than four servings in a six-cup coffee maker? Why?
11. Can the cost of operating an electrical heating appliance be estimated before the appliance is purchased?

Experiment 16

Name____________________

ELECTRICAL HEATING APPLIANCES

Location____________________

Date____________________

I. Study of Appliances Which Are Often Used for Long Periods of Time

Appliance	I_a	E_v	R_o	Watts	Cost per Hr. at $____ per K.W.H.	Calories per Hour

II. Study of Appliances Which Are Generally Used for Short Periods of Time

Appliance	I_a	E_v	R_o	Watts	Time	Cost at $____ per K.W.H.

III. Efficiency of an Electrical Heating Appliance

Name of appliance		
Mass of water		
T_1		
T_2		
Output		
I_a		
E_v		
Time		
Input		
Efficiency		

Experiment 17

ELECTROLYSIS

PURPOSE: To determine the relationship between the mass of metal deposited and the quantity of electricity passed through the electrolytic cell, or, more specifically, to determine the electrochemical equivalent of copper.

APPARATUS: Electrolytic cell, an acid solution of copper sulphate, ammeter, rheostat, knife switch, 6-volt storage battery (or a source of low voltage DC current), analytical balance, weights, clock with second hand, sandpaper.

THEORY: Certain liquids, called **electrolytes,** have the ability to conduct a current of electricity; these liquids include aqueous solutions of acids, bases, and salts. Current enters and leaves the electrolyte by means of plates called **electrodes;** the positive electrode through which the current enters is the **anode,** and the negative electrode by which it leaves is the **cathode.** Chemical changes take place when the current passes through the cell, and the process is known as **electrolysis.** If a metal is deposited on the cathode, the process is called **electroplating.**

If a current is passed through a cell containing copper electrodes and a solution of copper sulphate, the positive copper ions (Cu^{++}) of the solution are attracted to the negative cathode, where they give up their charge and deposit as metallic copper, and the negative sulphate ions (SO_4^{--}) are attracted to the positive anode, where they react with the copper to form more copper sulphate, which in turn breaks up into ions. This process continues as long as energy is supplied to keep the ions in motion. The result is that the anode loses in weight, the cathode gains in weight, and the solution remains at the same concentration. (A double anode may be used—then both sides of the cathode are plated equally.)

The mass of metal deposited in a given time depends on the electrochemical equivalent of the material and the quantity of electricity passed through the cell. The **electrochemical equivalent** for a given material is the mass deposited by one coulomb of electricity.

$$M_g = KQ_c$$

where M_g = mass in grams

K = electrochemical equivalent

Q_c = quantity of electricity in coulombs

Since $Q_c = I_aT_s$

where Q_c = quantity of electricity in coulombs

I_a = current in amperes

T_s = time in seconds

the mass deposited may be found by

$$M_g = KI_aT_s$$

or

$$K = \frac{M_g}{I_aT_s}.$$

Reference: Avery, 272–277.

PROCEDURE: ***Electrochemical Equivalent of Copper.*** 1. Polish the cathode with fine sandpaper; then be careful all during the experiment not to touch the part which is to be plated, as the metal will not deposit on an oily surface. If the plate must be laid down, put it on a sheet of clean paper.

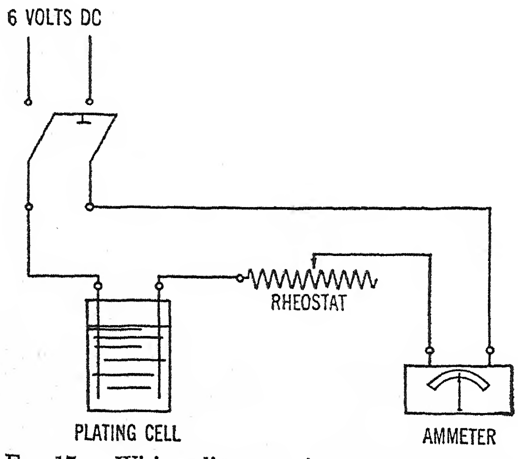


FIG. 17-a. Wiring diagram of apparatus used in electrolysis.

2. Connect the electrolytic cell, the ammeter, the rheostat (set for maximum resistance), and the knife switch in series with the DC source, with the current entering the cell through the two positive anodes (the two outer plates) and leaving through the negative cathode (the center plate). Lower the plates into the solution, taking care that the $CuSO_4$ solution does not come up to the clamps which hold the electrodes. Close the switch and adjust the rheostat until the ammeter reads about 1.5 amperes. Let the cathode plate for 5 minutes.

3. Remove the cathode, rinse it in distilled water, and dry it beside a Bunsen burner flame.

4. When the plate has cooled to room temperature, weigh it on the analytical balance.[1]

5. Replace the cathode and allow the current to flow for exactly 15 minutes. Keep the current constant by adjusting the rheostat.

6. Remove the cathode, rinse it, and dry it. When it has cooled to room temperature, weigh it as before.

7. Find the mass of metal deposited.

8. Calculate the electrochemical equivalent for copper.

9. Compare your result with the value given in the text and calculate the error and the per cent of error.

QUESTIONS:

1. Why is a copper plate used for the anode?
2. What is the advantage of using a double anode?
3. Is it necessary that the cathode be made of copper to do copper plating?
4. Can you suggest any reasons why the cathode should be made of copper for laboratory work?
5. Why is a direct current used? Why is it essential that it be kept constant in amount?
6. Should the loss in weight of the anode equal the gain in weight of the cathode?
7. What is meant by electrochemical equivalent?
8. What kinds of electroplating are found on articles used in the household?
9. List some plated articles which you have used in addition to those found in the house.
10. If all of the copper sulphate is not rinsed off the plate before it is dried and weighed, what will be the effect on the value of K?

[1] See Appendix A for directions for using an analytical balance.

Experiment 17

ELECTROLYSIS

Name____________________________

Location__________________________

Date_____________________________

Mass of cathode before plating	
Mass of cathode after plating	
Mass deposited on cathode	
Current	
Time	
Experimental value for K	
Standard value for K	
Error in experimental value	
Per cent of error	

Mass of cathode before plating
(List each weight separately)

Mass of cathode after plating
(List each weight separately)

Experiment 18

CHARACTERISTICS OF PARALLEL AND SERIES CIRCUITS

PURPOSE: To study the variations in current intensity, potential difference, and resistance when conductors are connected in parallel or in series.

APPARATUS: Lamps, ammeters, voltmeters, sockets, a 110-volt source of electrical energy (either AC or DC).

THEORY: The fundamental equation showing the relationship between current (I_a), potential difference (E_v), and resistance (R_o) is Ohm's law.

$$I_a = \frac{E_v}{R_o}.$$

The resistance may consist of one or several conductors; if there are two or more conductors, they may be joined in series or in parallel, or in a combination of series and parallel.

When conductors are connected in parallel, the current increases if the number of conductors is increased. The reason is that each new conductor offers another path for the flow of the electric current, or in other words, it increases the cross-sectional area of the conductor. The total current in the circuit may be found from

$$I = i_1 + i_2 + i_3 + \cdots$$

The potential difference is the same for each conductor. The total resistance may be found from

$$\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} + \cdots$$

or a more convenient form of the above equation written for three resistances is

$$R = \frac{r_1 r_2 r_3}{r_2 r_3 + r_1 r_3 + r_1 r_2}.$$

When conductors are connected in series, the current decreases if the number of conductors is increased. The reason is that each new conductor increases the length of the path through which the current flows and thus increases the resistance offered to its flow. The current is a constant for all points in the circuit. The potential difference varies with the resistance, and the total potential difference may be found from

$$E = E_1 + E_2 + E_3 + \cdots$$

The total resistance may be found from

$$R = r_1 + r_2 + r_3 + \cdots$$

Reference: Avery, pages 282–284 and 294–296.

PROCEDURE: *I. Resistances in Parallel.* 1. Wire a circuit containing an ammeter, three lamps connected in parallel, and a voltmeter; connect to the terminals of the service wires.

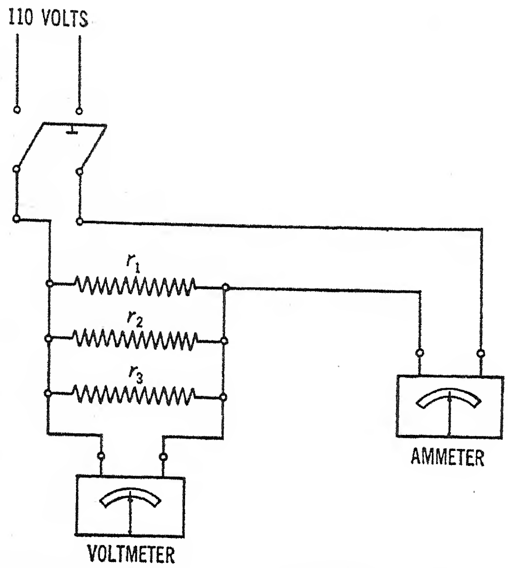


FIG. 18-a. Wiring diagram showing resistances wired in series.

2. Record ammeter and voltmeter readings for each lamp individually, and for three lamps operating simultaneously.
3. Calculate I, using the values for i_1, i_2, and i_3.
4. Compare the two values for I, and determine the difference between the two values.
5. Calculate r_1, r_2, r_3, and R from the ammeter and voltmeter readings.
6. Calculate R, using the values for r_1, r_2, and r_3 in the parallel resistance law.
7. Compare the two values for R, and determine the difference between the two values.

II. Resistances in Series. 1. Wire a circuit containing an ammeter, two lamps in series, and a voltmeter in parallel with one of the lamps; connect to the terminals of the service wires. (Note what happens if one lamp is loosened in its socket.)

2. Record ammeter and voltmeter readings with the voltmeter in parallel with each lamp individually, and then in parallel with both lamps.
3. Calculate E, using the values for E_1 and E_2.
4. Compare the two values for E, and determine the difference in the two values.
5. Calculate r_1, r_2, and R from the ammeter and voltmeter readings.
6. Calculate R, using the values for r_1 and r_2 in the series resistance law.
7. Compare the two values for R, and determine the difference between the two values.

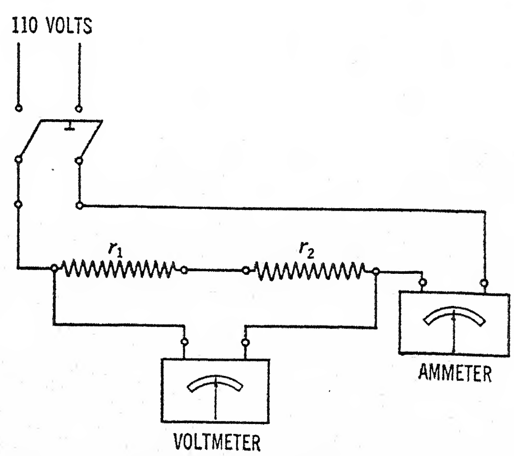


FIG. 18-b. Wiring diagram showing resistances wired in series.

QUESTIONS:

1. Will the lamps in the parallel circuit burn independently? Why?
2. Does the voltmeter reading remain approximately the same as the number of lamps in parallel is increased? Why?
3. Why does the ammeter reading definitely increase as the number of lamps in parallel is increased?
4. Why is the effective resistance for several lamps in parallel less than for any one of the individual lamps?
5. If each lamp in a parallel circuit has the same resistance, will $i_1 = i_2 = i_3$?
6. Will the lamps in the series circuit burn independently? Why?
7. In a series circuit does the ammeter reading remain approximately the same when the voltmeter connections are moved from one lamp to another? Why?
8. Why does the voltmeter read more when connected across two lamps in series than when connected across only one lamp?
9. Why is the resistance for several lamps in series more than for any one of the individual lamps?

10. If the resistances of two lamps in series are equal, will $E_1 = E_2$?
11. Are houses wired in parallel or in series? Give several reasons why.
12. How are small 15-volt lamps (Christmas tree lights) connected so that they may be used on a 120-volt circuit? How many lamps must be included in each set? What happens when one lamp burns out or is removed from the circuit?
13. Can you suggest the probable structure of the speed control on the sewing machine or the kitchen mixer? (If there is one in the laboratory, examine it.) How is this resistance connected with the motor?
14. Which factor in the formula

$$R = \frac{KL}{A}$$

where
R = resistance in ohms
K = specific resistance in ohms per centimeter cube
L = length of conductor in centimeters
A = cross-sectional area of conductor in square centimeters

is increased when resistances are connected in parallel? How does this affect the value of R? Which factor is increased when resistances are connected in series? How does this affect the value of R?

15. In a given circuit there are two groups of resistances in parallel. The first consists of three resistances in series—10, 20, and 30 ohms respectively. The second consists of two resistances in series—5 and 25 ohms respectively. The potential difference is 120 volts. Find the resistance of each branch, the current through each branch, the total resistance, and the total current. List each individual resistance and indicate the potential difference across it. Make a sketch of the circuit with the voltmeter connected where it will read 120 volts, and the ammeter where it will read the total current used.

Experiment 18

Name______________________________

Location___________________________

Date______________________________

CHARACTERISTICS OF PARALLEL AND SERIES CIRCUITS

I. Resistances in Parallel

Conductor	I_a	E_v	R_o
Lamp 1			
Lamp 2			
Lamp 3			
Three lamps			

$I = i_1 + i_2 + i_3$

$I =$ ____ $+$ ____ $+$ ____

$I =$ ________ amperes

Difference $=$ ____ $-$ ____

$=$ ________ amperes

$$R = \frac{r_1 r_2 r_3}{r_2 r_3 + r_1 r_3 + r_1 r_2}$$

$$= \frac{\quad \times \quad \times \quad}{\quad + \quad + \quad}$$

$=$ ________ ohms

Difference $=$ ______ $-$ ______

$=$ ________ ohms

II. Resistances in Series

Conductor	I_a	E_v	R_o
Lamp 1			
Lamp 2			
Two lamps			

$E = E_1 + E_2$

$E =$ ____ $+$ ____

$E =$ ________ volts

Difference $=$ ____ $-$ ____

$=$ ________ volts

$R = r_1 + r_2$

$=$ ______ $+$ ______

$=$ ________ ohms

Difference $=$ ______ $-$ ______

$=$ ________ ohms

Experiment 19

WAVE LENGTH AND VELOCITY OF SOUND

PURPOSE: To determine the velocity of sound in air at ordinary temperatures by measuring the wave length corresponding to a given frequency, and to determine the frequency of a fork.

APPARATUS: Resonance tube with water level arrangement for varying the length, several tuning forks, rubber mallet or rubber stopper, thermometer.

THEORY: The velocity at which sound travels in a medium may be determined from

$$v = ln$$

where
v = velocity
l = wave length
n = frequency.

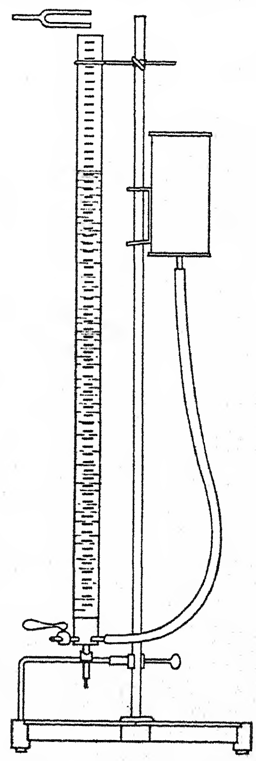


FIG. 19-a. Finding the length of a sound wave by resonance.

In this experiment a tuning fork of known frequency is used to produce a wave, the length of which may be measured by means of a resonating column of air. The air column is contained in a glass tube, the length of which is varied by changing the water level in the tube. When a vibrating tuning fork is held over the open end of the tube, air disturbances (compressions and rarefactions) travel down the tube and are reflected at the surface of the water. If these returning disturbances are in phase with those being sent out by the fork, resonance is indicated by a sudden increase in intensity of the sound.

Since these disturbances are reflected at the surface of the water, there will always be a node, or point of minimum disturbance, there. To have resonance, there must be an antinode, or point of maximum disturbance, at the fork. Therefore, to produce resonance, the length of the air column in the tube must be some odd-numbered quarter of a wave length ($\frac{1}{4}$, $\frac{3}{4}$, $\frac{5}{4}$, $\frac{7}{4}$, etc.).

It is found by experiment that the antinode is not exactly at the end of the tube, but a short distance x out from the tube. Thus,

$$d_1 + x = \tfrac{1}{4}\, l$$
$$d_2 + x = \tfrac{3}{4}\, l$$
$$d_3 + x = \tfrac{5}{4}\, l$$

where $\left.\begin{matrix} d_1 \\ d_2 \\ d_3 \end{matrix}\right\}$ = lengths of the respective resonance columns

x = distance of the antinode from the end of the tube
l = wave length.

But since

$$(d_2 + x) - (d_1 + x) = \tfrac{3}{4} l - \tfrac{1}{4} l$$

then

$$d_2 - d_1 = \tfrac{1}{2} l.$$

Likewise

$$(d_3 + x) - (d_2 + x) = \tfrac{5}{4} l - \tfrac{3}{4} l$$

and

$$d_3 - d_2 = \tfrac{1}{2} l.$$

Thus the factor x is eliminated from the equation, and the distance between any two successive resonance points is equal to one-half of the wave length.

The velocity of sound in air at 0° C. is 1087 ft. per sec. (or 331 meters per sec.). It increases approximately 2 ft. per sec. (or 0.6 meter per sec.) for each degree Centigrade rise in temperature, and approximately 1.1 ft. per sec. (or 0.34 meter per sec.) for each degree Fahrenheit rise in temperature.

Reference: Avery, pages 332–333 and 347.

PROCEDURE: ***I. Wave Length and Velocity of Sound.*** 1. Fill the resonance tube nearly full of water. Choose a fork of known frequency and start it vibrating by striking it on a rubber stopper. Then hold it above and very near to the end of the resonance tube in a position such that the prongs vibrate vertically.

2. Slowly lower the water level, and adjust for the maximum increase in intensity of the sound. Measure the length of the air column and record as d_1.

3. Continue lowering the water level until a second resonance position is found, and record the length of the air column as d_2.

4. Repeat this procedure three times. Calculate the wave length from each set of data and find the average value for the wave length.

5. Using the average wave length and the known frequency of the fork, compute the velocity of sound. Then compute the velocity for the existing temperature. Find the error and the per cent of error by comparing the experimental value with the value computed for the existing temperature.

6. Repeat parts 1–5 for a second fork.

II. Frequency of a Fork. 1. Choose a third fork and find the length of the wave emitted by it, using two positions of resonance. Make three determinations for each position.

2. Calculate the frequency of the fork, using the known velocity for the existing temperature and the experimental value for the wave length. Compare your answer with the frequency stamped on the fork. Find the error and the per cent of error.

3. Repeat the above procedure using a fork of different frequency.

QUESTIONS:

1. If the room had been warmer, would the water level have been higher or lower for each position of resonance?
2. Explain how air columns of different lengths may produce resonance with the same note.
3. Is the increase in sound more pronounced at the first or at the second position of resonance? Why?
4. If an organ pipe is in tune at 20° C., will it be pitched too high or too low if the temperature increases to 30° C.?
5. Which pipes produce the high notes in an organ—the longer or the shorter pipes?
6. Does the velocity of sound in air vary with changes in atmospheric pressure?
7. A tuning fork rated at 128 v.p.s. is held over a resonance tube. What is the shortest air column length at which resonance will occur at a temperature of 20° C.?

Experiment 19

WAVE LENGTH AND VELOCITY OF SOUND

Name ______________________________

Location ______________________________

Date ______________________________

I. Wave Length and Velocity

Temperature of air ________

d_1	d_2	$d_2 - d_1$	l	n	v		Error	Per Cent of Error
					Experimental	Computed		
Average l =								
Average l =								

II. Frequency of a Fork

d_1	d_2	$d_2 - d_1$	l	v	n		Error	Per Cent of Error
					Experimental	From Fork		
Average l =								
Average l =								

Experiment 20

LAWS OF VIBRATING STRINGS

PURPOSE: To verify the laws of vibrating strings.

APPARATUS: Sonometer, tuning forks (128, 256, and 512 v.p.s.), steel strings (0.036, 0.072, and 0.144 cm. in diameter), weights (a total of 17 kg., of which 16 kg. may be 1- and 2-kg. weights, and 1 kg. may be a set of fractional kilogram weights).

THEORY: If a tight string is set in vibration, it will emit a musical note, the pitch of which will be determined by the length, the tension, and the mass per unit length of the string. By varying any one of these factors, the pitch of the emitted tone may be changed.

The number of vibrations per second may be found from

$$n = \frac{1}{2\,l}\sqrt{\frac{t}{m}}$$

where

n = number of vibrations per second
l = length of vibrating segment
t = tension in the string
m = mass per unit length of the string.

Since the mass of a unit length is

$$m = \pi r^2 d$$

where

m = mass per unit length
r = radius of the string
d = density of the material

the equation for the number of vibrations may also be written

$$n = \frac{1}{2\,lr}\sqrt{\frac{t}{\pi d}}.$$

A **sonometer** is a long, hollow box, made of thin wood so that it will resonate like a violin body, with one or more strings stretched along its top. The strings pass over supports at A and B, and it is the section of string between these points which is to be considered. The length of this segment is varied by moving A. The string passes over a pulley wheel at C, and the tension in the string is varied by changing the weights W. By using various sizes of strings the effect of the change in the mass per unit length

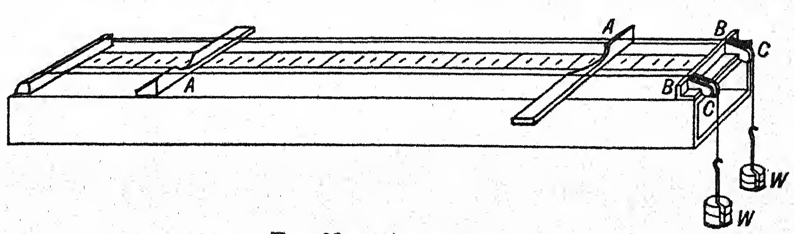


FIG. 20-a. A sonometer.

may be determined. If the strings are all of the same material, the mass per unit length will vary as r^2, since it is the only variable in $m = \pi r^2 d$. When the equation for finding the number of vibrations per second is examined, it will be noted that the frequency n is inversely proportional to the radius r.

Reference: Avery, pages 348–349.

PROCEDURE: *I. Variation of Frequency with Change of Length.* 1. The tension in the string and its mass per unit length are to be held constant. Use steel piano wire (0.036 cm. in diameter). Apply a load of 4 kg. at W and adjust A until the segment AB is in tune with a C-512 fork.[1] (Care should be taken not to stand where a string may strike one in the face if it breaks.)

2. Keep the tension constant and change the length of AB until it is in tune with the C-256 fork. Record the length of AB.

3. Keep the tension constant and again change the length of AB until it is in tune with the C-128 fork. Record the length of AB.

4. Express the ratio of the frequencies in terms of small, whole numbers. Express the ratio of the lengths in terms of small, whole numbers.

II. Variation of Frequency with Change of Tension. 1. The length of the string and its mass per unit length are to be held constant. Use steel piano wire (0.036 cm. in diameter). Make the length of AB equal to that required to tune the string with the C-256 fork as determined in Part I. Adjust the weights at W until the string is in tune with the C-128 fork. Record the tension.

2. Record the tension required to tune the string with the C-256 fork.

3. Adjust the weights at W until the string is in tune with the C-512 fork. Record the tension.

4. Express the ratio of the frequencies in terms of small, whole numbers. Find the square root of the tension in each case, and express the ratio of the numbers in terms of small, whole numbers.

III. Variation of Frequency with Change of Mass per Unit Length (Change in Radius). 1. The tension in the string and the length are to be held constant. Use steel piano wires (0.036, 0.072, and 0.144 cm. in diameter). Use the 0.036 cm. string first. Use the same length that was used in Part II, and the same tension that was required to tune the string with the C-512 fork. Record the data.

2. Change to the 0.072 cm. string, but use the same length and tension. Check with the C-256 fork, and record the data.

3. Change to the 0.144 cm. string, but use the same length and tension. Check with the C-128 fork, and record the data.

4. Express the ratio of the frequencies in terms of small, whole numbers. Express the ratio of the radii in terms of small, whole numbers.

IV. Study of Stringed Musical Instruments. 1. Study the strings of a piano, and note the variation in the length and the mass of the strings. Apply the laws which have just been verified on the sonometer.

2. Study the strings of a violin, or of some other stringed instrument, and apply the laws which have just been verified on the sonometer.

[1] If you have difficulty in determining when the string is in tune with the fork, fold a very small piece of paper in the form of a V and place it on the string at the center point of the segment AB. When the vibrating fork is set firmly on the sounding board, the string will begin to vibrate with sufficient energy to dislocate the paper if the adjustment is correct.

QUESTIONS:

1. Of what use is the box part of the sonometer?
2. Why is the paper thrown off the string when the string is in tune with the fork?
3. Why must the tuning fork be placed in contact with the sounding board?
4. If beats are heard when tuning a string to the frequency of a given fork, what does it mean?
5. How does a violinist make use of the change of frequency resulting from a change of tension?
6. How is the tension changed in the strings of a piano?
7. Why are the strings for the low notes of a piano wrapped with wire?
8. Where are the shortest strings of a piano? Do they have a high or a low pitch?
9. Is the iron framework on which the piano strings are stretched, fastened to the sounding board? Why?
10. Two strings of a violin which are approximately the same length vary in what factors?
11. Why are the strings used on a cello larger than those on a violin?
12. If a string under a tension of 5 kg. gives a note of 384 v.p.s., what frequency will it have if the tension is changed to 20 kg.?

Experiment 20

LAWS OF VIBRATING STRINGS

Name______________________________

Location____________________________

Date______________________________

I. Variation of Frequency with Change of Length
Tension and mass per unit length are constant

Tension (kg.)	Frequency (v.p.s.)	Frequency Ratio	Length (cm.)	Length Ratio
	512	4		
	256	2		
	128	1		

If the tension is constant, the frequency of vibration of a given string is ____________ proportional to the length.

II. Variation of Frequency with Change of Tension
Length and mass per unit length are constant

Tension (kg.)	$\sqrt{\text{Tension}}$	$\sqrt{\text{Tension}}$ Ratio	Frequency (v.p.s.)	Frequency Ratio	Length (cm.)
			128	1	
			256	2	
			512	4	

If the length is constant, the frequency of vibration of a given string is ____________ proportional to the ____________ of the tension.

III. Variation of Frequency with Change of Mass per Unit Length (Change in Radius)
Length and tension are constant

Length	Tension	Frequency (v.p.s.)	Frequency Ratio	Radius	Radius Ratio
		512	4		
		256	2		
		128	1		

If the length and tension are constant, the frequency is ____________ proportional to the radius of the wire, or the frequency is ____________ proportional to the ____________ of the mass per unit length.

Experiment 21

IMAGE FORMATION IN MIRRORS

PURPOSE: To locate the images formed by plane and spherical mirrors and to find the focal length of a concave and a convex mirror.

APPARATUS: Plane mirror, concave and convex spherical mirrors, optical bench and accessories, illuminated object box, convergent lens, ruler, pins, compass, protractor.

THEORY: Mirrors may be made either of metal with a brightly polished surface or of glass with a coating of silver. They may be either plane or curved and, if curved, they are usually either cylindrical, spherical, or parabolic. If the reflecting surface is the inner surface of the curve, the mirror is **concave**; but if the reflection is from the outer surface of the curve, the mirror is **convex.** The surfaces should be as nearly perfect as possible; otherwise, distorted images result. Most of the mirrors for household use are plane mirrors. Concave mirrors are used for headlight and searchlight reflectors, for reflectors on compound microscopes, and on reflecting astronomical telescopes. Convex mirrors are used for windshield mirrors, compact mirrors, and as ornamental reflecting surfaces.

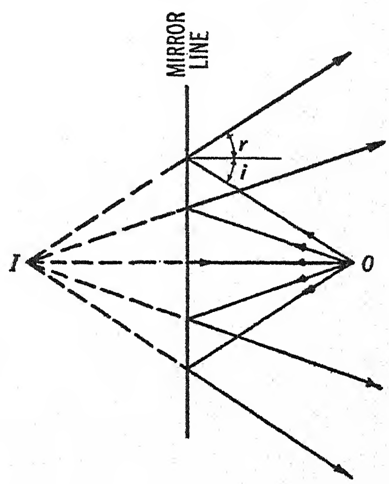


FIG. 21-a. Image formation in a plane mirror.

When a ray of light strikes a reflecting surface, part of it is reflected in such a way that the angle of incidence i and the angle of reflection r are equal. The **angle of incidence** is the angle between the incident ray and the normal at the point of incidence, and the **angle of reflection** is the angle between the reflected ray and the normal. As a consequence of this reflection law, the eye sees an image of an object in a plane mirror at a position back of the mirror from which the reflected rays seem to come. Since the rays do not actually pass through the image, it is known as a **virtual image** in contrast to a **real image** which is formed when the light rays actually do come to a focus to form an image. The image in a plane mirror is upright, the same size as the object, and as far back of the mirror as the object is in front of the mirror.

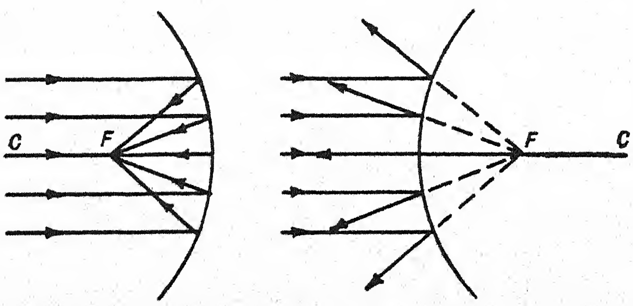


FIG. 21-b. Concave and convex mirrors.

When light rays are incident upon a spherical mirror, they are either converged to a real focus in front of the mirror or diverged so that they appear to come from a virtual focus back of the mirror. The center of the sphere of which the curved mirror is a portion is the **center of curvature** C, and the distance from C

to the mirror is the **radius of curvature.** The line connecting the center point of the reflecting surface and the center of curvature is the **principal axis** of the mirror. The **principal focus** F is the point at which rays parallel to the principal axis meet, or appear to meet, after reflection; it is located on the principal axis and is half-way between the mirror and the center of curvature. The distance from the mirror to the principal focus is the **focal length** of the mirror. When an object placed at one point causes an image to be formed at another point, the two points are known as conjugate foci. If the image is real, the positions of the object and of the image are interchangeable for any pair of conjugate foci.

It may be shown that

$$\frac{1}{D_o} + \frac{1}{D_i} = \frac{1}{F}$$

where D_o = distance of the object from the mirror
D_i = distance of the image from the mirror
F = focal length of the mirror.

The object distance is always positive. D_i is positive for real images and negative for virtual images. The focal length is positive for concave mirrors and negative for convex mirrors.

The images formed by concave mirrors may be either real or virtual, erect or inverted, and enlarged or reduced, depending upon the location of the object. If the object is beyond the center of curvature, the image is formed between the center of curvature and the principal focus; it is real, inverted, and reduced. If the object is between the center of curvature and the principal focus, the image is formed beyond the center of curvature; it is real, inverted, and enlarged. If the object is between the principal focus and the mirror, the image is formed back of the mirror; it is virtual, erect, and enlarged.

The images formed by convex mirrors are always back of the mirror between the mirror and the principal focus; they are virtual, erect, and reduced. As the object recedes from the mirror, the image moves from the mirror toward the principal focus.

The size of the image may be computed by using the following relationship, which is true for all mirrors:

$$\frac{\text{Size of object}}{\text{Size of image}} = \frac{\text{Distance of object from mirror}}{\text{Distance of image from mirror}}.$$

Reference: Avery, pages 368–373.

PROCEDURE: *I. Plane Mirror.* 1. Use a small plane mirror which is mounted on a block of wood, and place it on the data sheet with its reflecting surface exactly on the "mirror line" and at right angles to the plane of the paper. Insert a pin at the point O so that it stands erect.

2. To locate the image of this point, O, lay a ruler on the paper so that as you sight along its edge it points directly at the image of the pin. Draw a fine, sharp line along the edge of the ruler. Repeat this procedure until several lines have been constructed on each side of the point O. Remove the mirror and the pin. Extend the sight lines, using solid lines in front of the mirror and dotted lines back of the mirror. The point of intersection is the location of the image I of the point O.[1] Connect O and I, and record on the sketch and in the data tabulation the distances D_o and D_i, where D_o is the shortest distance from the object to the mirror and D_i is the shortest distance from the image to the mirror.

3. Draw solid lines from O to the intersections of the sight lines with the mirror line. These

[1] To locate the image of an object, locate the images of several points on the object, using two sight lines for each point.

lines represent incident rays and the sight lines represent reflected rays. Mark the lines with arrows to show the direction of the light rays along these paths.

4. At one of the points of reflection erect a normal to the mirror line. Label the angle of incidence i and the angle of reflection r. Measure each of the angles with a protractor, and record the number of degrees on the sketch and in the data tabulation.

II. Focal Length of a Concave Mirror. 1. The focal length of a concave mirror may be found by locating the point at which parallel rays come to a focus. Set up an optical bench so that one end is near a window. Place a concave mirror M in a mirror holder located at about 100 cm. from this end of the bench. The axis of the mirror should be parallel to the calibrated rod of the bench, and the mirror should be directed toward the window. Put a white cardboard screen S in another holder, which is between the mirror and the end of the bench, and have the plane of the screen normal to the calibrated rod. Adjust the position of the screen until a sharp image

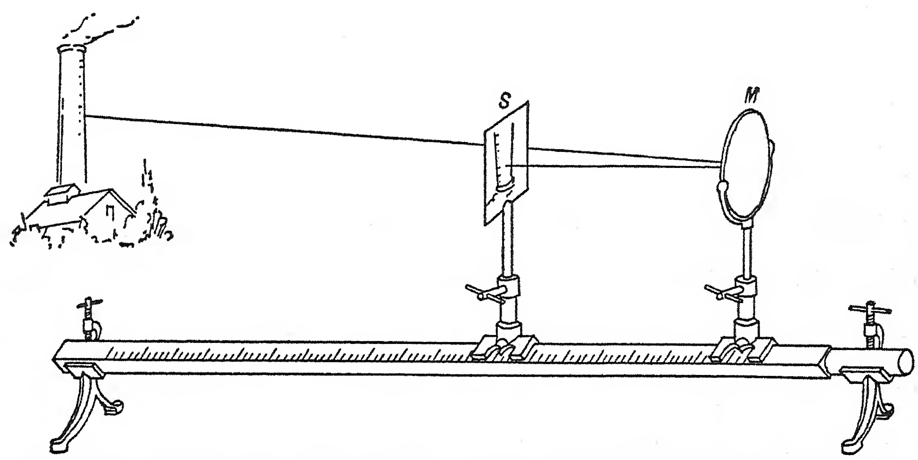


FIG. 21-c. Finding the focal length of a concave mirror by the use of parallel rays.

of some distant object is obtained. Since the rays from a distant object are parallel rays, the image will be formed at the principal focus. Repeat this procedure, using two other distant objects, and find the average of the three values for the focal length.

2. The focal length of a concave mirror may be found by locating conjugate foci. At the end of the optical bench nearer the window place the illuminated object box. Between the object and the mirror place the screen, which is adjusted to reach only to the lower edge of the object box with the division line between the object and the screen at approximately the height of the principal axis of the mirror. Light from the object box passes over the screen, strikes the mirror, and is reflected back to the screen. When the object and the screen are properly adjusted, a sharp image will appear on the screen on the side nearer the mirror. Record the distances D_o and D_i for four different positions of the object. In two cases place the object beyond the center of curvature, and for the other two place the object between the center of curvature and the principal focus. (For the last two positions lower the object and lift the screen until the top of the object box and the lower edge of the screen are at approximately the same height.) Using the mirror equation, calculate F from each set of data, and find the average of these values. Describe the image in each case as indicated on the data sheet.

III. Focal Length of a Convex Mirror. Since only virtual images are formed by convex mirrors they cannot be located on a screen, but the focal length of a convex mirror may be found by using a convex lens. Mount the lens between the object and the screen and adjust the position

of the screen until a sharp image is obtained. Note the position of the screen. Now mount the convex mirror between the lens and the image. The light will be reflected by the mirror, and when the position of the mirror is properly adjusted, the reflected image is formed beside the object. (Best results will be obtained if the mirror is near the lens.) When this adjustment is accomplished, the light rays are returning to the object over the same paths which they used in approaching the mirror. This is possible only if the light rays meet the surface of the mirror as normals and hence are radii of the spherical mirror; if produced, they intersect at the center of curvature. Since they do come to a focus when the mirror is not interposed, the image screen is at the center of curvature of the mirror, and the distance from the mirror to the screen is the radius of curvature of the convex mirror. Determine the radius of curvature and the focal length for three different settings. Find the average of the three determinations of the focal length.

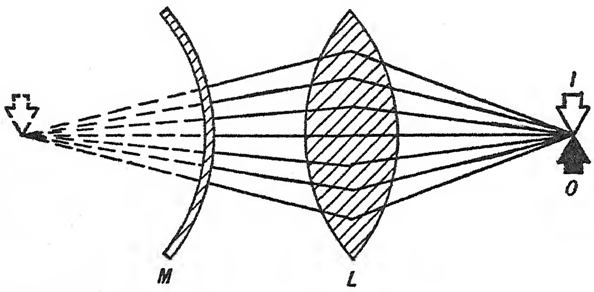


FIG. 21-d. Finding the focal length of a convex mirror by use of a convex lens.

QUESTIONS:

1. What are the requirements for a good mirror, whether plane or curved? What causes a "wavy" image?
2. How is it possible for a person to see several images of himself in triple mirrors?
3. What is really meant by the expression, "the image is behind the mirror"?
4. Are the reflectors in automobile headlights spherical or parabolic concave mirrors? Why?
5. Where should one stand in relationship to a concave mirror to see an enlarged, erect, virtual image of one's face?
6. How does the image of one's face appear in a convex spherical mirror? In a convex cylindrical mirror?
7. An image of the moon is observed in a spherical mirror. What is the approximate location of the image? Is it large or small?
8. Is the light which is reflected from a convex mirror scattered or brought to a focus?
9. Find the location of the image of an object which is 30 cm. from a concave mirror. The mirror has a focal length of 20 cm.
10. Find the location of the image of an object which is 30 cm. from a convex mirror. The mirror has a focal length of 20 cm.

Experiment 21

Name____________________

IMAGE FORMATION IN MIRRORS

Location____________________

Date____________________

I. Location of Image in a Plane Mirror

1. To locate the image of a point

$D_o =$ __________

$D_i =$ __________

$\angle i =$ __________

$\angle r =$ __________

Mirror Line

.O

II. Focal Length of Concave Mirror

1. By parallel rays

D_o	$D_i = F$
∞	
∞	
∞	
Average $F =$	

2. By conjugate foci

D_o	D_i	F	Image Is		
			Real or Virtual	Erect or Inverted	Enlarged or Reduced
Average $F =$					

III. Focal Length of Convex Mirror

By use of a convex lens

D_i TO MIRROR = RADIUS OF CURVATURE	F
Average F =	

Experiment 22

PHOTOMETRY

PURPOSE: To determine the candle power and the efficiency of several lamps and to study the variation in efficiency with change of voltage.

APPARATUS: Photometer with accessories, including suitable meters and rheostats, standard lamps, and lamps to be tested.

THEORY: **Photometry** deals with the measurement of the intensity of a light source. The unit for expressing this intensity is the **candle power,** which was originally the intensity of the English standard candle. Various standards have been used from time to time, but the Bureau of Standards at Washington, D. C., has standardized a series of incandescent lamps which are rated in terms of candle power, and which are used as standards in the United States.

The distribution of light from a point source is the same in all directions, and the resulting illumination at any given point varies directly with the intensity of the source but inversely as the square of the distance between that point and the light source. A unit for intensity of illumination is the **foot-candle** which is the intensity of illumination at a point one foot from a one-candle-power source.

$$I = \frac{CP}{d^2}$$

where I = intensity of illumination in foot-candles
CP = intensity of the light source in candle power
d = distance in feet between the source and the point at which the illumination is being measured.

The distribution of light about an incandescent lamp is not the same in all directions. If various determinations are made as the lamp is revolved about an axis normal to its base, it will be found that the values vary considerably. It is found that the average of any four values taken at positions which vary by 90° gives a fairly constant result for any one lamp. Since there will not be time for the student to measure the intensity at four positions, the lamps have been checked and a position found for each at which it gives an average candle power, and this position has been marked with a paper sticker. This average value is known as the average horizontal candle power.[1]

The efficiency of a lamp may be expressed in watts per candle power,

$$\text{Efficiency} = \frac{\text{watts}}{\text{candle power}}$$

[1] If the intensity is measured at various positions from the base to the top of the lamp, these values will be found to vary also. When such values are obtained, the results are generally presented graphically by plotting the intensities on polar coordinate paper.

or it may be expressed in candle power per watt,

$$\text{Efficiency} = \frac{\text{candle power}}{\text{watts}}.$$

This last ratio is not so generally used as the first, but it is a more logical way of expressing the efficiency. The efficiency is determined by the kind of filament used, the size of the lamp, the voltage at which it is operated, and the texture and color of the glass. Tungsten lamps are more efficient than carbon lamps, and large lamps are more efficient than small ones. The efficiency increases as the voltage increases because a larger percentage of the energy is turned into light as the temperature of the filament increases. Clear lamps are more efficient than frosted ones and white lamps are more efficient than colored ones.

The instrument which is used for comparing the intensities of light sources is a photometer. Many different types of photometers have been devised; the Bunsen, the Lummer-Brodhun, and the photoelectric photometers will be described here briefly.

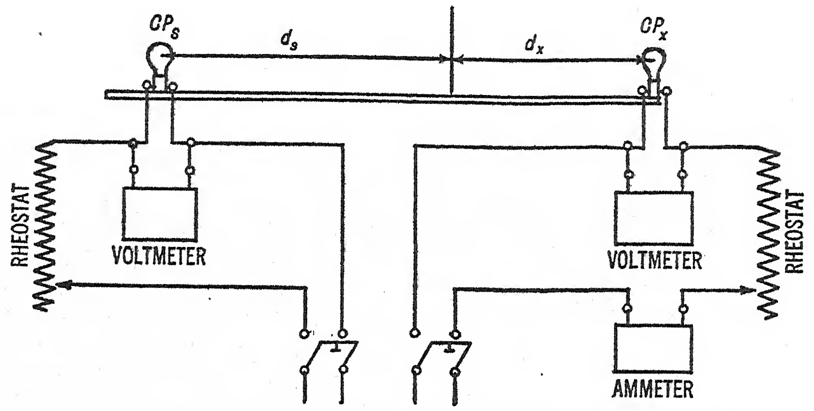


Fig. 22-a. A Bunsen photometer.

1. Bunsen Photometer. Essentially this is a white paper screen with a translucent spot in the center. The screen is placed between the two lamps which are to be compared so that the standard lamp illuminates one side of the screen and the unknown lamp illuminates the other side of the screen. The translucent spot appears darker than its surroundings on the side which is more brightly illuminated since it transmits more of the light. The relative positions of the lamps and the screen are adjusted until the screen is equally illuminated on both sides. Then the spot disappears or at least looks the same on both sides. (Mirrors which are set at an angle to the screen reflect images of each side of the screen to the observer so that he may observe the two images simultaneously.)

When the illumination is the same on each side,

$$\frac{CP_s}{CP_x} = \frac{d_s^2}{d_x^2}.$$

Since the candle power of the standard lamp is known and the two distances may be measured, the candle power of the unknown lamp may be calculated.

2. The Lummer-Brodhun Photometer. The general method of procedure is the same as with the Bunsen photometer, but the paper screen with the translucent spot is replaced by two right-angled prisms P_1 and P_2. Light from CP_s is diffusely reflected by the white screen R to the mirror M_s and then through the prisms to the telescope T. Light from CP_x is re-

flected from the other side of the screen R to the mirror M_x. The prisms P_1 and P_2 are alike except that P_1 has had a portion of its surface cut away so that the two prisms make contact only at the central part. The light which enters the telescope from CP_s must pass through this central spot, but that which is received from CP_x must be reflected from that part of the prism face surrounding the spot. When the entire field of view appears equally bright, the illumination is the same on both sides of the screen.

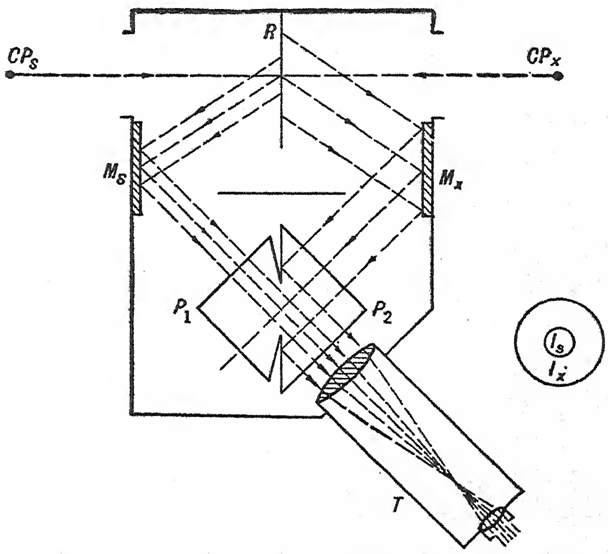


Fig. 22-b. Detail of a Lummer-Brodhun photometer.

3. Photoelectric Photometer. The photoelectric cell furnishes a method of determining the intensity of a light source in which no visual judgment is required. A current is generated when light falls on the cell, and in the particular type of cell used in photometers the magnitude of the current is directly proportional to the intensity of illumination which, in turn, is directly proportional to the intensity of the light source. The magnitude of the current is indicated by a galvanometer.

In one type of photoelectric photometer the standard lamp and the unknown lamp are not burning at the same time. The standard lamp is placed where its rays will fall directly on the light-sensitive surface and the deflection of the galvanometer is noted, as well as the distance from the standard lamp to the photoelectric cell. Then the unknown lamp is placed where its rays will fall directly on the cell and the distance between the lamp and the cell adjusted until the deflection of the galvanometer is the same as that caused by the standard lamp. The distance from the lamp to the cell is noted. Since the intensity of illumination is equal in the two cases, the following relationship is again true:

$$\frac{CP_s}{CP_x} = \frac{d_s^2}{d_x^2}.$$

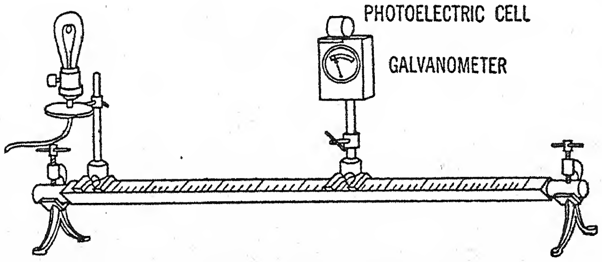


Fig. 22-c. A photoelectric photometer.

The galvanometer may be calibrated in terms of foot-candles. In this case no standard lamp is required since $CP = Id^2$.

Reference: Avery, pages 267–269 and 379–382.

PROCEDURE: *I. Candle Power and Efficiency of Various Lamps.* 1. In making photometric measurements, it must be possible to keep the voltage across a lamp at any desired amount. Therefore, a voltage source is chosen which is higher than the desired voltage, and a rheostat is wired in series with each lamp in order that the voltage across the lamp may be adjusted to the desired amount; a voltmeter is wired in parallel with each lamp. An ammeter is also wired in series with the unknown lamp. If a visual determination is made, the standard lamp should be of the same type as the test lamp. Keep the voltage across the standard lamp the same as that at which it was calibrated. Always turn the lamps so that the paper stickers

face the screen. The standard lamps were calibrated in this position and the test lamps have been checked and the stickers placed where an average horizontal candle power for the lamp will be measured.

2. Find the candle power and the efficiency for each of several lamps. For each lamp, record the kind of filament and the size and color of the lamp. Also state whether the lamp is clear or frosted and whether it is evacuated or gas-filled.

3. If equipment is available, test the candle power of some of the new lamps which have no metal filament but in which the current is transmitted by an ionized gas.

II. Variation in Efficiency with Variation in Voltage. 1. Record at least three sets of data for one lamp, varying the voltage across it and using at least one voltage below normal and one above normal. Be sure to keep the voltage across the standard lamp at the voltage at which it was calibrated.

2. Calculate the candle power and the efficiency of the lamp for each voltage. Note whether the efficiency increases or decreases as the voltage increases.

QUESTIONS:

1. What factors affect the candle power of a lamp?
2. Why does the intensity of illumination vary inversely as the square of the distance from the source?
3. Why is the light from an incandescent lamp not equal in all directions? Will there be a greater variation around a clear lamp or around a frosted lamp? Why?
4. Which is the more efficient—an evacuated bulb or a gas-filled bulb? Why?
5. How does frosting a lamp affect its efficiency? Why?
6. How does colored glass affect the efficiency of a lamp?
7. How does colored glass affect the color of the light given out by a lamp?
8. One often hears that blue glass increases the amount of blue light given out by a lamp. Is this true? Just what is the result if blue glass is used?
9. Why is a lamp more efficient at high voltage?
10. If lamps are more efficient when operated at a higher temperature, why are they not made to operate at a higher temperature in actual use?

Bunsen photometer

11. Why does the translucent spot appear brighter than the surrounding field on the side of the screen which is less brightly illuminated?
12. What are some of the factors which make it difficult to judge whether the intensity of illumination is the same on each side of the screen?

Lummer-Brodhun photometer

13. Why does the light from CP_s form a circle in the telescope while the light from CP_x forms a ring around this circle?
14. Describe the field observed in the telescope when the unknown lamp is nearer the prisms than it should be for equal illumination.

Photoelectric photometer

15. What is the advantage of the photoelectric photometer over the other two types?
16. Explain just why a photoelectric cell which has been calibrated in terms of foot-candles may be used for determining the candle power of a lamp without the use of a standard lamp.

Experiment 22

PHOTOMETRY

Name______________________________

Location____________________________

Date_______________________________

I. Candle Power and Efficiency of Various Lamps

Characteristics of Standard Lamp [1]	CP_s	d_s	Characteristics of Test Lamp [1]	CP_x	d_x	I_a	E_v	Watts	Efficiency

II. Variation in Efficiency with Variation in Voltage

Characteristics of Standard Lamp [1]	CP_s	d_s	Characteristics of Test Lamp [1]	CP_x	d_x	I_a	E_v	Watts	Efficiency

[1] Include information as to kind of filament, color of glass, clear or frosted, evacuated or gas-filled, and, for the standard lamp, the voltage at which it was calibrated.

Experiment 23

ILLUMINATION

PURPOSE: To study the factors which influence the intensity of illumination due to direct and reflected light.

APPARATUS: Foot-candle meter, several reading and floor lamps, small model rooms in which to study illumination.

THEORY: Intensity of illumination is measured in foot-candles; a **foot-candle** is the intensity of illumination at a point one foot from a source of one candle power. The number of foot-candles at any point may be measured with a **foot-candle meter,** which consists of a photoelectric cell connected in series with a sensitive galvanometer calibrated in foot-candles. The photoelectric cell used in this type of meter contains a plate coated with a light-sensitive material which emits electrons when light falls on it, and this emitted stream of electrons constitutes an electric current. The magnitude of the current is directly proportional to the intensity of the light which falls on the cell.

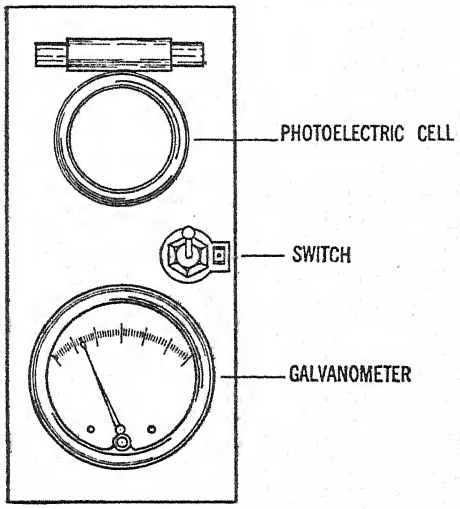


FIG. 23-a. A foot-candle meter.

At any given point the intensity of illumination due to direct light from any given lamp is directly proportional to the candle power of the lamp and inversely proportional to the square of the distance between that point and the source of light.

$$I = \frac{CP}{d^2}$$

where I = intensity of illumination in foot-candles

CP = candle power of the lamp

d = distance in feet between the source of light and the point at which the illumination is being measured.

Any shade or reflector which is placed on a lamp influences the distribution of the light furnished by it. The total amount of light, however, is decreased, since there are no perfect reflectors or transmitters of light energy. The intensity at any given point may be increased by reflecting to this point the light which is given out in another direction. The illumination at a given point may be due entirely to reflected light; that is, there may be no light received directly from the lamp. In this case the color and texture of the reflecting surfaces become important factors in determining the intensity of illumination. The foot-candle meter gives information concerning only one of the factors which enter into the problem of illumination —it measures intensity. It gives, however, no information as to the color or quality of the light.

In order to study the changes in illumination which are due to the ceiling, wall, and floor finishes, to the size and color of the lamp, and to the type of reflector, two small rooms (about 24 × 24 × 12 in.) are provided. Each is equipped with a ceiling fixture which may be connected to any 110-volt source of current. One side of each room is hinged so that it may be opened easily. The interior of one room is painted with dull, black paint; the other with glossy, white enamel. A foot-candle meter is provided in which the photoelectric cell is at the end of a long cord instead of being built into the same unit as the galvanometer. The cell is placed on the floor in the center of the room facing upward, and the cord leading from it passes through a notch in the lower edge of the door.

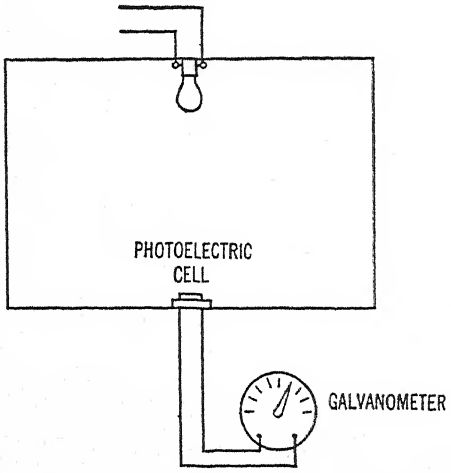


Fig. 23-b. Measuring the change in illumination due to changing the color and texture of the ceiling, walls, and floor.

For a given lamp in the dark room, the reading of the foot-candle meter is a measure of the light which comes directly from the lamp to the cell, since there is no reflected light. If the same lamp is then used in the white room, the increase in the meter reading is a measure of the reflected light. A variety of ceiling, wall, and floor coverings is provided, as well as a variety of sizes and colors of lamps. Reflectors for indirect and semi-direct lighting are also provided.

Reference: Avery, pages 376–392.

PROCEDURE: *I. Survey of Illumination in the Building.* 1. Measure the number of foot-candles at your table, without the ceiling lights on and with the ceiling lights on. Place the foot-candle meter on the table, facing upward. According to the list of standards supplied with the foot-candle meter, is the illumination as great as it should be? Does the increase due to turning on the ceiling lights indicate that the illumination at night due to these lights is as great as it should be?

2. Measure the illumination near a window. (Care must be taken to avoid exposing the meter to an intensity greater than it is capable of measuring.) If the room has more than one exposure, measure the illumination near another window which faces in a different direction. Measure the illumination in the part of the laboratory which seems to you to have the least amount of light.

3. Measure the illumination in the hall outside of the laboratory, both with the lights off and with the lights on.

4. Measure the illumination in the main lecture room with the lights off and with the lights on, noting at the same time the type of illumination which is used there. (Make the measurements near the middle aisle at the first row of chairs, and place the meter, facing upward, on the arm rest of a chair.)

5. Measure the illumination in the center of the apparatus room with the doors closed and the ceiling lights off, and then with the ceiling lights on. Is the illumination sufficient for locating the apparatus?

6. In the office opening off the laboratory, the size of the room and the finish of the walls are somewhat comparable to those found in a small living room. Seat yourself in a chair and hold the foot-candle meter about where you would hold a newspaper, and note the readings for the various conditions noted on the data sheet.

7. Measure the illumination at the wall at a point about 6 ft. from the floor lamp. Then turn

the meter so that it responds to the light reflected from the wall, being careful not to hold the meter between the wall and the source of light.

II. Study of Effect of Changing Reflecting Surfaces. 1. Place a small lamp in the ceiling fixture in the black room. Put the photoelectric cell in place and close the door. Record the meter reading.

2. Put the same lamp in the white room and record the meter reading.

3. Arrange various interiors by thumb-tacking ceiling and wall coverings in place and changing the floor covering if desired. The lamp may be used without, and then with, a reflector. On the data sheet describe the interiors and reflectors which you used.

QUESTIONS:

1. What factors influence the intensity of illumination if the light is received directly from the source?
2. What factors influence the intensity of illumination if the light is received by reflection?
3. Why are the foot-candle meters provided with several scales? On which scale is the instrument the most sensitive?
4. How is a light bulb made which has three intensities?
5. What per cent is the illumination increased when the lamp is moved from the black room to the white room?
6. Which changes the meter reading more—a change in the color of the ceiling or of the side walls?
7. How many foot-candles will result at a point 6 feet from a 100-watt lamp if the efficiency of the lamp is 0.8 watt per candle power?
8. If the light which falls on a given surface is 8 foot-candles while that reflected is 5 foot-candles, what per cent of the light is reflected?

Experiment 23

ILLUMINATION

Name____________________

Location____________________

Date____________________

I. Survey of Illumination in the Building

1. Illumination at your table = ________ (no ceiling lights)

   According to data furnished with the meter, the illumination should be about ________

   Illumination at your table = ________ (ceiling lights on)

   Increase due to ceiling lights = ________

   This increase indicates that the illumination at night due to these lights will ________________

2. Illumination near a ________ window = ________ at ________ (time)

   Illumination near a ________ window = ________ at ________

   Illumination in darkest part of laboratory = ________ at ________

   (This last measurement was made ________________________ (location))

3. Illumination in hall (lights out) = ________ at ________

   Illumination in hall (lights on) = ________ at ________

4. Illumination in main lecture room (lights out) = ________ at ________

   Illumination in main lecture room (lights on) = ________ at ________

   (________________ lighting is used in the main lecture room)

5. Illumination in the center of apparatus room (doors closed, lights off) = ________, which ________ sufficient for locating the apparatus.

   Illumination in the center of the apparatus room (doors closed, lights on) = ________, which ________ sufficient for locating the apparatus.

6. Illumination in office (door closed)

   No artificial light = ________

   Ceiling lights on = ________

   Floor lamp on low = ________

   on medium = ________

   on high = ________

   Floor lamp, high, shade removed = ________

   Indirect lighting unit = ________

7. Illumination at wall ________ ft. from lamp = ________

   Reflected light from wall at same place = ________

II. Effect of Changing Reflecting Surfaces

Room	Foot-Candles
1. Black	
2. White	
3.	
4.	
5.	
6.	

Experiment 24

CONVEX AND CONCAVE LENSES

PURPOSE: To determine the focal lengths of several convex and concave lenses and to study the images formed by these lenses.

APPARATUS: Optical bench and accessories, convex and concave lenses, illuminated object box.

THEORY: Lenses are widely used in spectacles, opera glasses, microscopes, telescopes, cameras, and other optical instruments. They are of two general types: (1) **convex, positive,** or **convergent,** and (2) **concave, negative,** or **divergent.** A convex lens is thicker at the center than at the circumference and brings parallel light rays to a real focus on the side of the lens away from the source of light. A concave lens is thicker at the circumference than at the center and causes parallel light rays to diverge as if they came from a virtual focus on the side of the lens toward the source of light.

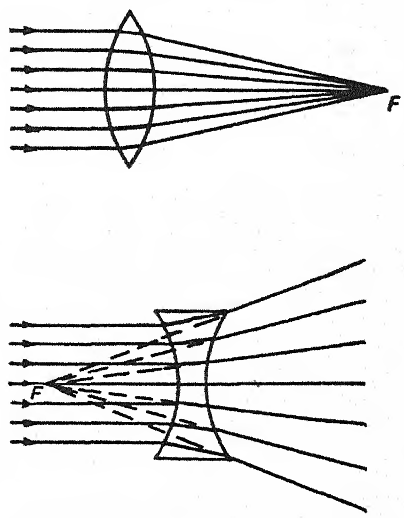


FIG. 24-a. Convex and concave lenses.

The center point of a lens is its **optical center.** A line drawn normal to the diameter of the lens and through the optical center is known as the **principal axis** of the lens. The **principal focus** is the point on the principal axis where rays parallel to the principal axis come to a focus or appear to come to a focus. The distance from the optical center to the principal focus is the **focal length** of the lens. For any lens, it may be shown experimentally that

$$\frac{1}{D_o} + \frac{1}{D_i} = \frac{1}{F}$$

where
D_o = distance of object from lens
D_i = distance of image from lens
F = focal length of the lens.

D_o is positive for a real object and negative for a virtual object; D_i is positive for a real image and negative for a virtual image; F is positive for a convex lens and negative for a concave lens. The magnification is found by

$$\frac{\text{Size of object}}{\text{Size of image}} = \frac{\text{Object distance}}{\text{Image distance}}.$$

One method of finding the focal length of a convex or positive lens is to place the lens between the object and the screen and adjust the positions of the object and of the screen until a clear image is formed on the screen. A large number of such locations are possible. As the object

approaches the lens on one side, the image recedes from the lens on the other side. The size and location of the image vary, depending upon the location of the object with respect to the lens and to the principal focus. (1) If the object is far from the lens, the image is real but smaller than the object, and inverted. (2) If the object is near the lens but still outside the focal length, the image is real but larger than the object, and inverted. As the object is brought toward the lens, there is a point where the distance of the object is equal to the distance of the image,

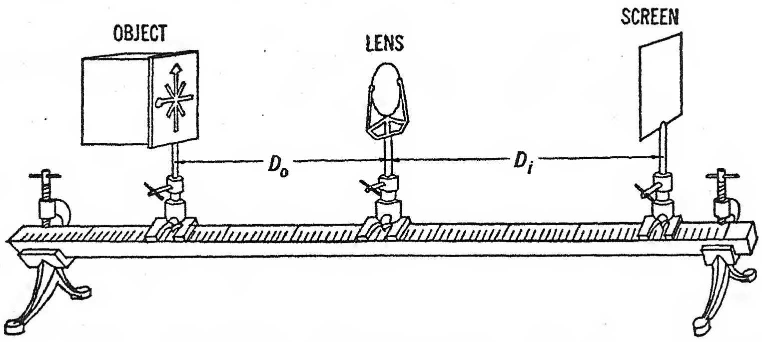


FIG. 24-b. Showing the relative positions of the object, the lens, and the screen on the optical bench.

and the size of the object is equal to the size of the image. These distances are equal to twice the focal length. (3) If the object is within the focal length, the image is on the same side of the lens as the object, is virtual, and approaches the lens from infinity as the object moves from the principal focus to the lens. Since these images are virtual, they cannot be located on a screen.

In finding the focal length of a concave or negative lens, a somewhat different method is used. Since a concave lens diverges the rays, it forms a virtual image which cannot be located on a screen. A convex or positive lens may be used with the concave lens to converge the rays before they strike the concave lens in order to produce a real image. If the convex lens forms an image at I, the introduction of a concave lens between the convex lens and the real image I will cause the rays to converge farther back at I'. The focal length may be determined by substituting the measured values of D_o and D_i in the lens formula.

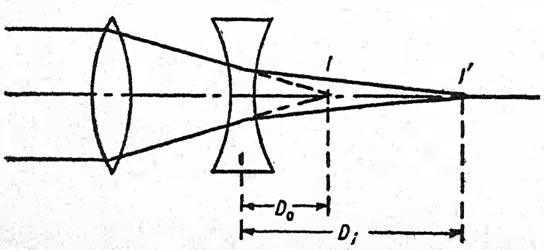


FIG. 24-c. Finding the focal length of a concave lens.

Reference: Avery, pages 393–394 and 397–399.

PROCEDURE: *I. Convex Lenses.* 1. Place a convex or positive lens in a holder at the 100-cm. graduation on the optical bench. Place the illuminated object box 60 to 90 cm. from the lens. Adjust the screen until a sharp image of the object is formed. (Care should be taken to have the plane of the lens normal to the axis of the optical bench, and it will be found that the positions are more accurately located if a small circular aperture is placed between the object and the lens, but close to the lens. This reduces spherical aberration and produces a sharper image.) Record D_o and D_i. Calculate the focal length of the lens. Note whether the image is larger or smaller than the object.

2. Leave the lens at the 100-cm. graduation, but place the screen 100 cm. from the lens. Adjust the object distance until a sharp image appears on the screen. Record D_o and D_i. Calculate the focal length of the lens. Note whether the image is larger or smaller than the object.

3. Place the object so that its distance from the lens is equal to twice the focal length. Ad-

just the screen until a sharp image is obtained. Record D_o and D_i. Note the size of the image in relation to the size of the object.

4. Repeat steps 1–3, using a convex lens of a different focal length.

II. Concave Lenses. 1. Place a convex or positive lens at the 100-cm. graduation on the optical bench. Place the illuminated object 60 to 90 cm. from the lens. Adjust the screen until a sharp image I is formed. Note the position of this image since it is to serve as the object for the concave lens. Now interpose a concave or negative lens between the convex lens and the image, and move the screen back until a sharp image I' is obtained. The distance from the concave lens to the image I is D_o, and the distance from the concave lens to the image I' is D_i. Note the signs carefully. Find the focal length of the concave lens.

2. Repeat the above procedure for two other positions of the object.
3. Find the average focal length of the concave lens.

QUESTIONS:

1. Why is the small circular aperture introduced between the object and the lens?
2. How would the image appear if the center of the lens were covered and only those rays which pass through the outer part of the lens were allowed to fall on the screen?
3. How can you distinguish between a real image and a virtual image?
4. A simple magnifying glass is a convex lens. Where must the object be in relation to the principal focus of the lens in order that the image be erect and enlarged? Is the image real or virtual?
5. The human eye contains a convex lens. Does this mean that the real images formed on the retina are inverted? Does the sensation received in the brain make the object appear inverted? How do you explain this?
6. A person who is far-sighted wears a convex spectacle lens, and one who is near-sighted wears a concave spectacle lens. In each case what do these lenses do to the light rays before they enter the eye?
7. Is the distance from the spectacle lens to the eye lens ever greater than focal length of the lens?
8. Is it true that everyone sees an object most distinctly when it is 10 in. from the eye? Why?
9. If a penny is 19 mm. in diameter and a silver dollar is 38 mm. in diameter, at what distance from a convergent lens of 20 cm. focal length must the penny be placed to make the image as large as a dollar?
10. Make geometric sketches, approximately to scale, to locate the position and size of the images formed by a convex lens. Use the ray which passes through the optical center of the lens and the one which is parallel to the principal axis. Have the distance of the object from the lens:

    a. Over twice the focal length
    b. Twice the focal length
    c. Less than twice the focal length
    d. Equal to the focal length
    e. Less than the focal length.

    From your sketches and from the information in your data and sketches, fill in the following summary concerning images formed by a convex lens.

    Kind: Real or virtual
    Size: Larger or smaller than object
    Form: Erect or inverted
    Position: Location of image with respect to the principal focus.

Distance of Object from Lens	Image			
	Kind	Size	Form	Position
Over twice the focal length				
Twice the focal length				
Less than twice the focal length				
Equal to the focal length				
Less than the focal length				

Experiment 24

Name________________________

CONVEX AND CONCAVE LENSES

Location________________________

Date________________________

I. Convex Lenses

Lens 1

D_o	D_i	F	Relation of Size of Image to Size of Object
1.			Image is than object
2.			Image is than object
Average $F =$			
$2F = 2 \times \quad = \quad$ cm.			
3.			Image is object

Lens 2

D_o	D_i	F	Relation of Size of Image to Size of Object
1.			Image is than object
2.			Image is than object
Average $F =$			
$2F = 2 \times \quad = \quad$ cm.			
3.			Image is object

II. Concave Lens

D_o	D_i	F	Relation of Size of Image to Size of Object
1.			As the object recedes from the lens, the image becomes ________ but the image is never ________ the principal focus.
2.			
3.			
Average $F =$			

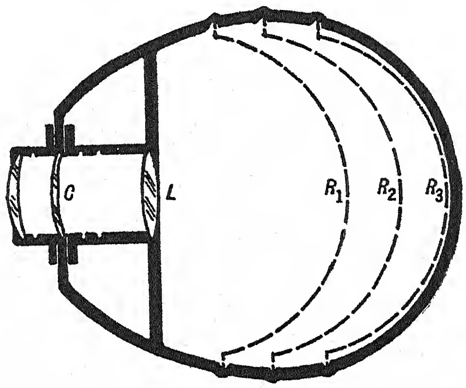
Experiment 25

THE OPTICAL PRINCIPLES OF THE EYE[1]

PURPOSE: To study the eye as an optical instrument, with the aid of an eye model and various kinds of lenses.

APPARATUS: Ingersoll eye model and a set of lenses.

THEORY: The Ingersoll eye model which is used in this experiment consists essentially of a water-tight tank 18 cm. long and 13 cm. deep, shaped roughly like the elongated horizontal section of the eyeball. At the front end of this vessel an aperture is provided which is fitted with a meniscus lens to represent the cornea. At a distance of about 4 cm. behind the cornea



C = cornea

L = lens

R_1 = position of retina for far-sighted eye

R_2 = position of retina for normal eye

R_3 = position of retina for near-sighted eye

FIG. 25-a. A horizontal section of the eye model.

is a low partition to indicate the division of the eyeball into two compartments, one of which in the eye is filled with the aqueous humor and one with the vitreous humor. Behind the aperture or pupil and extending slightly beyond the partition, is a semi-cylindrical holder in which various kinds of lenses may be placed with their axes in line with the center of the cornea. A similar holder attached in front of the cornea is intended to hold various kinds of correcting lenses. On each side of the tank are three vertical grooves, each pair of which is intended to fix a position for a curved metal screen. The circular white area on the screen represents the retina, and the black spot at one side of the retina represents the blind spot or the small area of the retina which is not sensitive to light. The three pairs of grooves are designed to hold the retina in positions corresponding to those found in a far-sighted, a normal, and a near-sighted eye. When in use, the tank is filled to within about 2 cm. of the top with water, which takes the place of the humors in the eyeball. The opaque walls of the model shield the inside so that all the phenomena may be studied without the necessity of darkening the room. Reference to the diagram in Fig. 25-a, which represents a plane view of the arrangement described, will assist in making the details clearer.

The study of the optical principles of the eye with the aid of the eye model consists of the

[1] Adapted from Exp. L-51, *The Optical Principles of the Eye*, published by the Central Scientific Company.

examination of the images formed on the retina. The images are always real, but the student must determine in each case whether the image is: sharp or blurred, erect or inverted, enlarged or reduced. To facilitate the study, a brightly illuminated "object" is provided, consisting of a metal housing containing an incandescent lamp, in front of which is a ground glass diffusing screen and a metal plate perforated with a radially slotted pattern. The vertical slot of this pattern terminates in a triangular enlargement, and the horizontal slot in a circular enlargement. The object may be placed on the table in front of the eye model; when so placed, its center is at the same height as the center of the cornea.

Six simple lenses and one metal diaphragm, contained in a suitable case, are part of the equipment. Each lens and the diaphragm are held in metal rings with small handles. Each lens is marked on the handle of the ring to indicate the kind of lens and its strength in diopters.

$$\text{Strength in diopters} = \frac{1}{\text{Focal length in meters}} \text{ or } \frac{100}{\text{Focal length in centimeters}}.$$

The following lenses comprise the set:

1. Double convex, +7.00 diopters
2. Double convex, +20.00 diopters
3. Double convex, +2.00 diopters
4. Double concave, −1.75 diopters
5. Concave cylindrical, −5.50 diopters
6. Convex cylindrical, +1.75 diopters.

No. 1 and No. 2 of these lenses serve in turn as the lens of the eye, and the others are used either in the eye to produce "defects" of vision or in front of the eye to correct defects. Each of the cylindrical lenses has short scratches at opposite ends of a diameter to indicate the direction of the cylindrical axis.

Reference: Avery, pages 395–397.

PROCEDURE: *I. Accommodation.* 1. Fill the tank within about 2 cm. of the top with clear water. Set up the model so that it "looks at" a window or other bright object four or five meters away. With the retina in the middle or normal eye position, insert the weaker (+7) of the two "eye lenses" in the groove just above the low partition. The image of the object at which the model is pointed should be in focus on the retina. Note the character of the image, whether sharp or blurred, erect or inverted, and its size as compared with the size of the object. The image formed on the retina corresponds exactly to the image formed in a camera on the photographic plate. Note the probable effect on one's perception of that part of the image which falls on the blind spot.

2. Next use as the object the lamp box with the radially slotted pattern and place it 33 cm. from the cornea. At this object distance the image will be much blurred until the weaker lens (+7) is replaced by the stronger lens (+20). This illustrates the process of accommodation or focusing, which in the eye is automatically accomplished by a set of muscles that change the curvature of the eye lens.

II. Far- and Near-Sightedness. 1. With the lamp box placed at 33 cm. as before and with the +20 lens serving as the lens of the eye, make the eye far-sighted by moving the retina to the forward position. Examine the spherical lenses +2.00 and −1.75, and determine whether a converging or a diverging lens should be used for correcting the defect and bringing the image to a sharp focus on the retina. Test the conclusion by placing the correcting lens which you select in front of the eye and noting whether or not it sharpens the image.

2. Make the eye near-sighted by moving the retina to the rearmost position, and repeat the above experiment.

III. Astigmatism. 1. Using the lamp box at 33 cm. and the retina in normal eye position, insert immediately behind the cornea the cylindrical concave lens marked −5.50, thereby producing astigmatism. (In the human eye astigmatism is generally due to a slight cylindrical curvature of the cornea; therefore in the model a change of cornea would be the logical way of producing astigmatism; but since this is impracticable, the same purpose is accomplished by the insertion of an additional lens.) By rotating the cylindrical lens, it will be found that one line only of the object pattern can be made sharp while the others are blurred.

2. Now place in front of the cornea the correcting convex cylindrical lens marked +1.75 and turn it until the entire image is again sharp. Notice the relative directions of the cylindrical axes in the two lenses.

IV. Compound Defects. Astigmatism is frequently accompanied by far- or near-sightedness. Combine tests II and III, using both a cylindrical and spherical correcting lens at the same time in front of the cornea. Adjust the positions of the lenses until the entire image is sharp. In actual practice the two correcting lenses are, of course, combined in a single compound eyeglass lens.

V. Effect of Pupil Size or Vision through a Small Aperture. Select any case in which the image is not quite clear, insert the diaphragm with the 13-mm. hole either just in front of or just behind the cornea. This shows that a very small aperture in front of the eye will sharpen the image. Decide on the reason for this.

VI. Vision without the Lens of the Eye. In some diseases of the eye (e.g., cataract) the lens of the eye must be removed. Vision is still possible, however, by the use of a suitable correcting lens. Remove the eye lens and place the +7 lens as a simple magnifier in front of the cornea. A clear image is formed if the object is brought very near to the eye.

VII. Action of a Simple Magnifier. With the retina in the center set of grooves, use the stronger lens (+20) as the lens of the eye. Place the lamp box 33 cm. in front of the eye model. Now introduce the +7 lens as a simple magnifier in front of the cornea. For a clear image the eye model now must be moved nearer to the object until its distance is only about a third of its former value; the image will accordingly be about three times as large. This test shows that a magnifying glass enables the eye to get close to the object and still see it distinctly. Note in this connection that, for close work, the near-sighted eye has an advantage over the normal eye. With the stronger (+20) lens, lamp at 33 cm., and retina at normal eye position, note the approximate size of the image. Then make the eye near-sighted and move the object until the image is again sharp; it will, of course, be considerably larger. This would indicate that a near-sighted jeweler might, with the naked eye, do some work for which a man with normal vision would require a magnifying glass.

At the conclusion of the experiment be sure that no lenses are left in the model and then empty it. Clean the lenses with a little absorbent cotton and replace them in the box.

QUESTIONS:

1. As the eye changes its focus from a far object to a near object, does the crystalline lens become more convex or less convex? Why?
2. By what means is the curvature of the lens of the eye changed?
3. What is meant by accommodation?
4. Why must the object box in this experiment be placed at a certain given distance rather than at just any distance?

5. What is the physical defect in the structure of the eye if it is far-sighted? What kind of lens is required to correct this defect?
6. What is the physical defect in the structure of the eye if it is near-sighted? What kind of lens is required to correct this defect?
7. What causes astigmatism, and how may it be corrected?
8. How may one lens correct both near-sightedness and astigmatism, or far-sightedness and astigmatism?
9. Why does a small aperture in front of the lens increase the sharpness of the image?
10. How is it possible for a person to see without a lens in the eye?
11. What is the blind spot in the eye?
12. Why is it possible to see a large image of an object which is held very near the eye if a positive lens is interposed between the object and the eye?

Experiment 25

THE OPTICAL PRINCIPLES OF THE EYE

Name______________________________

Location____________________________

Date______________________________

I. Accommodation

With +7 lens and a distant object, image is (sharp, blurred), (erect, inverted), (enlarged, reduced).

With +7 lens and a near object, image is (sharp, blurred).

With +20 lens and a near object, image is (sharp, blurred), (erect, inverted), (enlarged, reduced).

II. Far- and Near-Sightedness

In a far-sighted eye the eyeball is too (short, long), and the rays come to a focus in (front, back) of the retina. In this experiment a __________ lens is used to correct the defect.

In a near-sighted eye the eyeball is too (short, long), and the rays come to a focus in (front, back) of the retina. In this experiment a __________ lens is used to correct the defect.

III. Astigmatism

The cylindrical axis of the +1.75 lens must be (parallel, at right angles) to the cylindrical axis of the −5.50 lens to correct the astigmatism caused by the latter lens.

IV. Compound Defects

To correct far-sightedness and astigmatism, the ________ lens and the ________ lens are used.

To correct near-sightedness and astigmatism, the ________ lens and the ________ lens are used.

V. Pupil Size

As the pupil size (increases, decreases) the image becomes sharper.

5.

6.

7.
8.
9.
10.
11.
12.

APPENDIX A

To Plot a Curve

The following directions will be helpful in plotting curves:

1. Use coordinate paper with suitable rulings.
2. Indicate the variables, and the units in which they are measured, on the x- and y-axes.
3. Choose a suitable scale and indicate it with small numerals at intervals on the axes. The curve should usually be drawn to as large a scale as the paper will allow.
4. Indicate the position of each point with a small circle or cross.
5. Join the points with a smooth curve which approximates the points (unless directed to draw straight lines from point to point). If one or two points decidedly distort the curve, their locations should be rechecked.
6. Append a descriptive title in a vacant corner of the sheet. If several curves have been plotted on one sheet, number the curves and indicate the sub-titles for the individual curves in a legend under the main title.

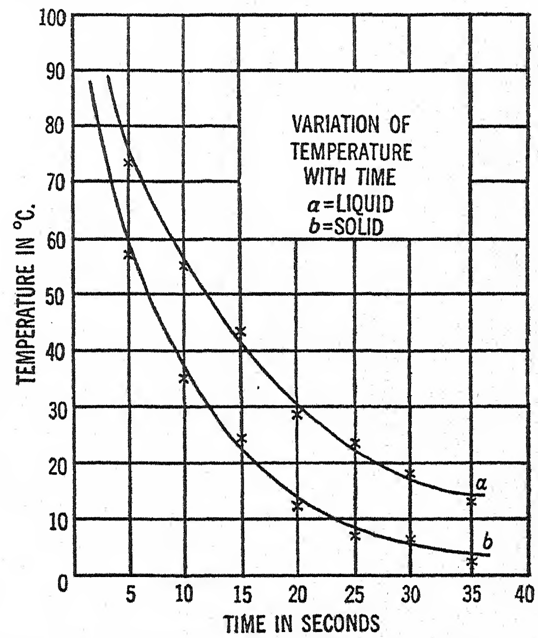


Fig. A-1. Showing the method of plotting a curve.

To Read a Mercury Barometer

A mercury barometer consists of a tube of mercury inverted in a reservoir of mercury. As the atmospheric pressure varies, the height of the mercury in the tube varies. To read a mercury barometer:

1. Adjust the level of the mercury in the reservoir R by means of the screw S until the mercury just touches the tip of the white pointer P. When properly adjusted, the pointer and its image in the mercury appear to touch each other.
2. Stand so that the eye is level with the top of the mercury column. Turn the screw at the right of the barometer until the movable vernier scale V meets the top of the mercury column, i.e., the front and back edges of the tube and the mercury meniscus are all in line.
3. Read the barometric height in either metric or English units as desired.
4. Since the density of the mercury and the length of the scale are influenced by the temperature, these readings may be reduced to standard conditions by

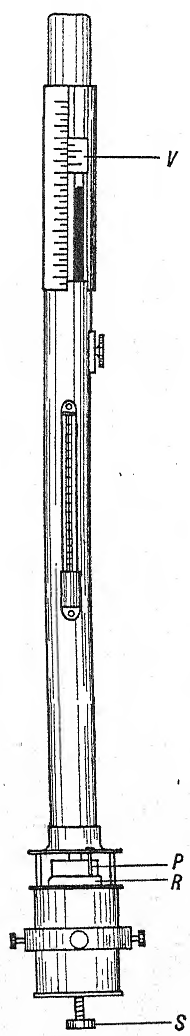


Fig. A-2. A mercury barometer.

$$h_o = h_t - 0.00016 \times t \times h_t$$

where h_o = height of mercury column in millimeters at 0° C.
t = temperature in degrees Centigrade
h_t = height of mercury column in millimeters at temperature t

or the correction may be found by consulting tables in the *Handbook of Chemistry and Physics.*

To Use an Analytical Balance

An analytical balance may be used when very accurate weighing of small articles is required. It is an extremely sensitive equal-arm balance, enclosed in a glass case to protect it from moisture, dust, and air currents, which affect its accuracy. The case rests on three supports, two of which are adjustable. The balance may be leveled by means of a spirit-level. This is a small cup, with a curved glass cover, completely filled with alcohol except for a small air bubble which is always at the highest point. This bubble is at the center of the glass cover when the scale is level.

There are supports under the scale pans which are controlled by a knob K. To release the pans, K is pushed away from the observer, and if it is then turned to the right, the pan supports are locked in the lowered position. To support the pans, K may be turned to the left and allowed to spring gently toward the observer. The beam of an analytical balance rests on a knife-edge bearing, which is usually made of either hard steel or agate. The beam should be lifted slightly from its bearing when the balance is not in use, to avoid unnecessary wear on the bearing; this is accomplished by turning the screw S to the right. The beam may be lowered so that it will rest on the bearing by turning S to the left as far as it will turn. The object is usually placed on the left pan, and the weights on the right pan. A small rider is usually provided which may be placed on the beam to aid in obtaining a balance.

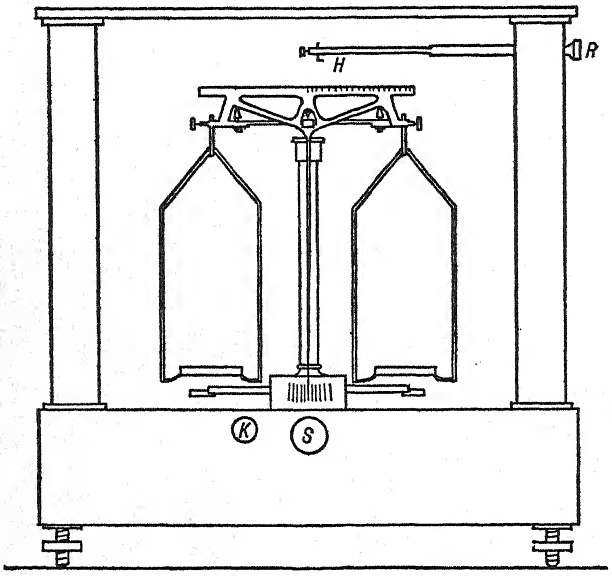


FIG. A-3. An analytical balance.

The following precautions should be observed when using an analytical balance:

1. Level the scale before using it.
2. Do not move or jar the scale after it is leveled.
3. Keep the glass case closed except when adding or removing objects or weights.
4. Keep the pans and beam supported except when using the scale.
5. Lift the beam from its bearing whenever any object or weight is added to, or taken off, either scale pan, or when the rider is adjusted on the beam.
6. Handle the weights with forceps. (These are special weights for use with analytical balances only.)
7. Never overload the scale.
8. Never put powders or liquids directly on the scale pans but use a paper, a watch glass, or a beaker as a container.

To use the balance:

1. Place it on the table in a convenient location directly in front of the observer, and then level it.
2. Lower the pan supports and then lower the beam so that it rests on the knife-edge bearing. The pointer will probably begin to move over the scale; if it does not, open the window and wave the hand in front of the balance until the resulting air currents cause the pointer to swing through eight to twelve scale divisions. (If the pointer moves decidedly farther to one side of the scale than to the other, ask the instructor to adjust the balance for you.)
3. Since the pointer swings for some time, it is not practicable to wait for it to come to rest, and if only reasonable accuracy is required, the rest point may be assumed to be midway between two successive turning points. This is known as the apothecaries' method of obtaining rest points.
4. Lift the beam from its bearing and place the object on the left scale pan. On the right scale pan place what you judge to be the approximate weights required to balance the object.

5. Lower the beam and note whether the weights are too light or too heavy. Again lift the beam and adjust the weights. Continue this process, using the various weights in a systematic order, until the pointer swings practically the same number of spaces on either side of the rest point.

6. Count the weights on the scale pan. Since the smallest weight in the box is 0.001 gm., the weight of the object may be assumed to be accurate within ± 0.001 gm.

7. Instead of using any weights smaller than 0.01 gm., a rider may be used. It is a small wire stirrup which may be placed on the beam by means of the hook H which is operated from the outside of the case by the rod R. The position of the rider may be adjusted until the pointer swings equally on either side of the rest point. The beam is divided into ten large divisions on either side of its mid-point, and each large division is subdivided. The rider weighs 0.01 gm., and if it is placed at the tenth division on the right end of the beam, it has the same weight value as if it were placed on the pan. For smaller displacements from the center, it has proportionally smaller weight values. Therefore the weight of the object may be determined within ± 0.0001 gm. if such accuracy is required.

8. For still greater accuracy a set of readings may be taken to determine the rest point. A set of readings consists of five consecutive turning points, three on one side and two on the other side. The average turning points on the left and on the right are calculated, and then these two numbers are averaged. The data and calculations should be recorded as follows:

Left	Right
5.0	16.3
5.6	15.7
6.1	2)32.0
3)16.7	16.0 = average right
5.6 = average left	5.6 = average left
	2)21.6
	10.8 = rest point

Then the object is placed on the left scale pan and the weights are adjusted on the right side until a balance is obtained. This may be checked very closely if readings are recorded as explained above and the weights adjusted until the same rest point is obtained.

APPENDIX B

Notes for the Instructor

The following notes are merely suggestions as to suitable apparatus. No attempt has been made to list catalog numbers for each piece of apparatus needed. The numbers from the catalog of the Central Scientific Company are preceded by CSC, those from the Chicago Apparatus Company by CAC, and those from the W. M. Welch Scientific Company by WSC.

General Apparatus

Trip scale, CSC 3470; CAC 40430; WSC 4041
Overhead beam balance, CSC 2680; CAC 40300; WSC 4035
Analytical balance, CSC 1000; CAC 40200; WSC 4000B
Platform balance, CSC 7260; or one purchased locally
Spring balance, CSC 5800; CAC 40860; WSC 4086
Platform spring balance, CSC 6560; CAC 40580; WSC 4053; or one purchased locally
Hall's carriage, CSC 75850; CAC 8900; WSC 818
Inclined plane, CSC 75840; CAC 8850; WSC 809
Steam generator, CSC 77935; CAC 9650; WSC 1625
Calorimeter, CSC 77970; CAC 9680; WSC 1689

Exp. 1. Household Weights and Measures

Standard liquid measures, CSC 72860 B and C or 72865 A, B, and C; CAC 2810; WSC 148
Standard dry measures, CSC 26575; WSC 146B
Standard weights, Henry Troemner, Philadelphia, Pa.
Standard yardstick, W. and L. E. Gurley, Troy, N. Y., 9000

Exp. 2. Density and Specific Gravity

Trip scale—English, CSC 3360 A or B; WSC 4040B
Weights, CSC 8960; WSC 4040C
Graduates, CSC 16100; CAC 64830 H; WSC 5256
Hydrometers, CSC 16780, 16760 A, B, and C, and 16835; CAC 5090, 5080, and 66720; WSC 1126, 1128, and 2325
Hydrometer jars, CSC 14501 C; CAC 5150 G; WSC 1141

Exp. 3. Graphical Composition and Resolution of Forces

Force table, CSC 74285; CAC 7920; WSC 740
Spring balances, CSC 5700 and 5800; CAC 2150 and 40860; WSC 4082 and 4086

Exp. 4. Breaking Strength of Textile Materials

Jolly balance, CSC 7550; CAC 40600; WSC 4060
Spring with sensitivity of 0.2 gm. per cm. for cotton
Spring with sensitivity of 1 gm. per cm. for wool
Eyelets made of any fine wire
Microscopes, compound

The thread and cloth testing devices have been made in this laboratory. Detailed sketches will be furnished on request.

Exp. 5. Moments of Force and Simple Machines

Demonstration balance, CSC 75565; CAC 7780; WSC 743
Pulleys, CSC 75650; CAC 8230; WSC 765
Weight holders, CSC 9612, with weights 9600; CAC 42495, with weights 42585; WSC 785, with weights 787

Exp. 6. Vacuum Cleaners

A varied selection of cleaners
Rugs (27 × 54 in.) should be of like quality if the results for various machines are to be comparable. Use fairly heavy, close-napped rugs to give the machines a real test.
Dirt should be typical of the locality (i.e., clay, sand, etc.). It may be screened through a 0.01-in. mesh sieve.
Wattmeter, 0–375, 0–750 watts

Exp. 7. Thermometers

The usual laboratory grade Centigrade thermometer (−20° to 110°) is generally accurate enough for a standard, and an inexpensive Fahrenheit thermometer (−20° to 120°) will generally have appreciable errors.

Exp. 8. Change of State

Water trap, CSC 77945; CAC 9680; WSC 1629

Exp. 9. Freezing and Boiling Points of Solutions

These simple experiments are often used in lecture demonstrations, but the student usually has to be told what temperature changes are taking place—therefore, the advantage of letting the student make the tests himself.

Exp. 10. Pressure Cookers and Pressure-Temperature Curves for Water Vapor

Commercial pressure cookers with thermometer holders attached
Thermometer holders may be purchased from the Denver Pressure Cooker Company, Denver, Colo.

Exp. 11. Fuels

Parr calorimeter assembly may be purchased from Parr Instrument Company, Moline, Illinois.
Sargent gas calorimeter assembly, CSC 20700, or
Junker calorimeter, CSC 20710; CAC 10020; WSC 1704
Gas meter, CSC 20740
Gas plates and kettles may be purchased locally. Effect on efficiency of kind of kettle, kind of burner, ratio of size of kettle to size of burner, ratio of air to gas, etc., may be studied.

Exp. 12. Insulating Properties of Building Materials

The boxes used for this experiment have been described. It is important to insulate the walls so as to decrease heat exchanges except through the material in question.
Samples of insulation materials may be purchased locally.

Exp. 13. Moisture Content of the Atmosphere

Hygrometers
Mason type, CSC 76970 and 76990; CAC 74610 and 74630; WSC 1280
Recording hygrograph, CSC 76995; CAC 74650; WSC 1285
Humidiguide, CSC 76965; CAC 74670; WSC 1279A
Sling psychrometer, CSC 77005; CAC 74600; WSC 1290
Hygrodeik, Taylor Instrument Companies; CAC 74640; WSC 1292

Exp. 14. Household Motors

Double range ammeters and voltmeters are suggested. They are much more convenient to use when the speed of the appliance is changed from high to low. Ranges depend upon appliances chosen.

Exp. 15. Heat Equivalent of Electrical Energy

Calorimeter, CSC 78044, and heater 78072; WSC 1693A, and heater 1693
Ammeter, 0–1, 0–2 amperes
Voltmeter, 0–75, 0–150 volts

Exp. 16. Electrical Heating Appliances

Ammeters, voltmeters, and wattmeters of suitable ranges for the appliances chosen. Double range ammeters are more convenient.

Exp. 17. Electrolysis

Copper voltameter, CSC 81120; CAC 16980; WSC 2350
Ammeter, 0–1, 0–2 amperes
Rheostat, CSC 82910 or 82900; WSC 2751 or 2748H

Exp. 18. Characteristics of Parallel and Series Circuits

Double range ammeters and voltmeters
Selection of lamps for resistances

Exp. 19. Wave Length and Velocity of Sound

Resonance apparatus, CSC 84930; CAC 20450; WSC 3309
Forks, CSC 84560 J and K; CAC 20000 No. 9 and No. 10; WSC 3225 and 3227

Exp. 20. Laws of Vibrating Strings

Sonometer, CSC 85065; CAC 20740; WSC 3352B
Sonometer wires, CSC 85085; CAC 20790; WSC 3358; plus one steel wire 0.056 in. in diameter
Weights, CSC 9650; CAC 42550; WSC 3362
Forks, CSC 84560 B, C, and K; CAC 20000 Nos. 2, 3, and 10; WSC 3211, 3213, and 3227

Exp. 21. Image Formation in Mirrors

Single rod optical bench with accessories
Concave mirror (F = 25 cm.), CSC 85405; CAC 21640; WSC 3522
Convex mirror (F = 25 cm.), CSC 85415; CAC 21660; WSC 3520
Optical object box, CSC 85605

Exp. 22. Photometry

Bunsen photometer, CSC 86395; CAC 21350; WSC 3578
Lummer-Brodhun photometer, CSC 86460; CAC 21410; WSC 3577A
Photoelectric cell, CSC 80915, with base 86127; CAC 19570, with base 19610; WSC 2148, with base 3580

Exp. 23. Illumination

Foot-candle meter, Weston 603 or 614

Exp. 24. Concave and Convex Lenses

Single rod optical bench with accessories
Convex lens, CSC 85645 H and J; CAC 21680 A and B; WSC 3416 and 3418
Concave lens, CSC 85650 E; CAC 21690 A or B; WSC 3438

Exp. 25. Optical Principles of the Eye

Ingersoll eye model, CSC 87660